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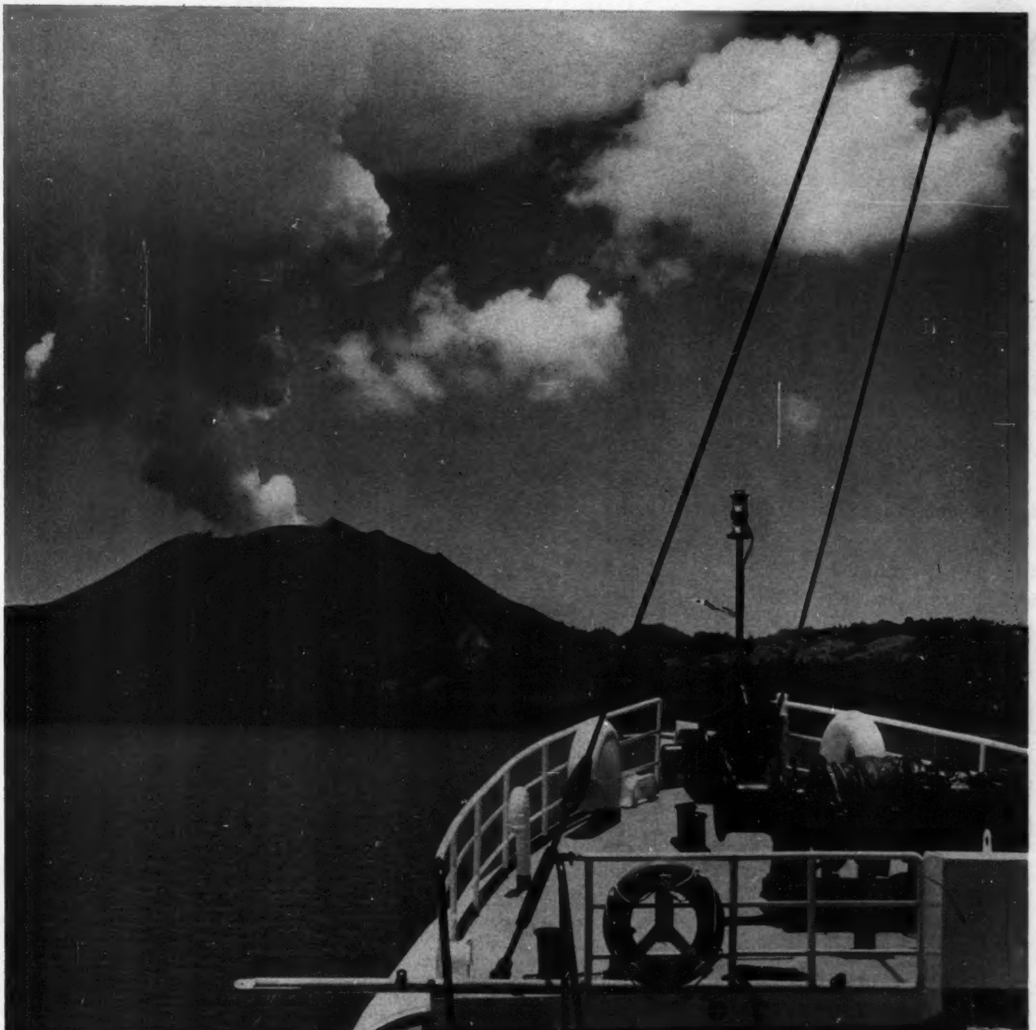

Marianas Fishery Resources

Marine Fisheries REVIEW

On the cover: A NOAA research vessel, the *Townsend Cromwell*, nears an active volcano on Pagan Island in the Marianas while conducting research in the region. Photo by Jeffrey Polovina; see the article on page 19.

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Molluscan Mariculture in the Greater Caribbean: An Overview

DARRYL E. JORY and EDWIN S. IVERSEN

Introduction

This paper reviews the history and current status of both experimental and commercial molluscan mariculture in the greater Caribbean area (Fig. 1). Seafood is and has been a staple for Caribbean people since pre-Columbian times. In many areas, however, seafood demand exceeds both the current catch and potentially available resources. A recent review of eastern Caribbean fisheries by Olsen et al. (1984) incorporated land area, human population, shelf area, number of tourists, and fish landings by island/nation. These figures, together with total seafood consumption rates (local residents and tourists), permitted a comparison between island-shelf potential yield and demand for marine protein in the Caribbean which revealed that:

1) Only a few of the eastern island nations are currently supplying their own seafood demand,

2) The current demand for seafood in the area is about 775,000 metric tons (t), which greatly exceeds both current landings of about 87,000 t and the 200,000 t potential yield, and

3) The shelf area of many islands is

ABSTRACT—Marine mollusks suitable for mariculture in the Caribbean area have received increased attention in recent years in an effort to produce more seafood for inhabitants of the area. However, molluscan mariculture in the Caribbean is still, with a few exceptions, in its infancy when compared with these activities elsewhere. Pilot and commercial culture operations for American oysters, Crassostrea virginica, *and mangrove oysters,* C. rhyzophorae, *exist in Jamaica, Cuba, Venezuela, and Mexico, and for rock mussels,* Perna perna, *in Venezuela. Extensive research has been carried out on the mariculture potential of the queen conch,* Strombus gigas, *with experimental hatcheries in some countries (more are under construction or planned), and a commercial hatchery is already operating in Turks and Caicos. The culture potential of several mollusks in the Caribbean, including native and exotic species, and several problems impeding increase in molluscan culture in the Caribbean are discussed.*

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Figure 1.—Map of greater Caribbean region.

Figure 2.—Mangrove oyster culture system in coastal region.

generally too small to support additional fishing effort, and although there are some areas that can support additional exploitation, increased seafood production must come from resources not already exploited.

Although almost all island nations presently have this serious seafood production deficit, some nations are in more trouble than others. For example, the Dominican Republic, which currently lands about 6,435 t of finfish and shellfish, has a seafood demand of 137,000 t and a potential yield from its shelf of only 864 t.

Mollusk culture could increase seafood production in many Caribbean island nations and reduce the difference between present production and demand. Another reason for culturing mollusks in the Caribbean is that as export products (for food or the aquarium or ornamental shell trade) they generate hard currency to help alleviate serious trade deficits that characterize many Caribbean nations, as well as provide needed employment. Finally, cultured mollusks, in particular cephalopods (Hanlon, In press) and the sea hare, *Aplysia* spp. (Fay, 1971), can and have been used extensively in neuroscience and behavioral research.

However, despite these incentives, molluscan culture in the greater Caribbean is, with few exceptions, in its infancy when compared with the status of these activities in such countries as Japan, Australia, France, Spain, the Netherlands, and others. In addition, available information on the molluscan culture in the Caribbean is limited. In contrast, the journal *Aquaculture* (Morse et al., 1984) devoted over 400 pages to "Recent innovations in cultivation of Pacific mollusks." Possibly because of the vastness of the Pacific Ocean and variety of marine habitats and molluscan species, the research effort is more extensive than in the Caribbean. Nonetheless, the importance of increasing food production in the Caribbean is every bit as important as it is in the Pacific, and perhaps even more so considering the large human population and the relative lack of other food sources in many Caribbean island nations.

Present molluscan mariculture activities in the Caribbean can be divided into three categories: Semi-intensive culture, extensive culture, and research.

Semi-intensive Culture

In the Caribbean, semi-intensive culture of mangrove oysters, *Crassostrea rhizophorae*, is presently practiced in Cuba and Jamaica, while American oysters, *C. virginica*, are raised in Mexico and Venezuela, and the South American rock mussel, *Perna perna*, is cultured only in Venezuela.

Cuba

Over a 12-year period (1963-74), biological and ecological studies and breed-

ing experiments supervised by United Nations Development Program/Food and Agriculture Organization (UNDP/FAO) experts, were conducted on mangrove oysters in Cuba, and many locations were found suitable for culture. A mangrove oyster culture system was developed during the study period, based on known methods and the use of inexpensive and readily available local materials (Nikolic et al., 1976).

Farming facilities, generally located in estuarine areas, consist of stockades of palm posts driven into muddy or sandy bottoms, arranged in line or in a quadrangle (Fig. 2). Posts extend about 1-1.5 m above the surface of the water and are placed 2.5 m apart, supporting 6 m long, wooden traverse beams. Red mangrove terminal branches, suspended from the traverse beams with tarred ropes or monofilament nylon thread, are used as spat collectors. The collectors are checked at least once a month (Fig. 3) to make certain that the binding ropes are securely fastened, that collectors are favorably located in terms of tidal cycles, and to remove fouling organisms and predators. The oysters are harvested 5-6 months after placing the collectors. Subsequent harvests take place each month thereafter, when the largest oysters are collected during monthly cleaning operations. (Nikolic et al., 1976).

The first commercial oyster farm in Cuba, located on the northeastern shore, began operating in 1975. About 30 farms were initially planned by Cuban officials, with an estimated potential production between 6,500 and 7,500 t. However, because of industrial pollution in the culture areas, only about 20 percent of the area could be used. Presently there are 19 farms in operation, with an estimated potential production between 900 and 1,100 t of unshucked oysters. In the last 3 years, wide fluctuations in seasonality and abundance of spat settlement have adversely affected growout schemes. To optimize oyster growout, it is necessary to have an adequate, consistent source of spat. A hatchery under construction and supervision of FAO experts, combined with ongoing pilot scale research on controlled reproduction and oyster larval maintenance, is expected to produce sufficient spat consistently[1].

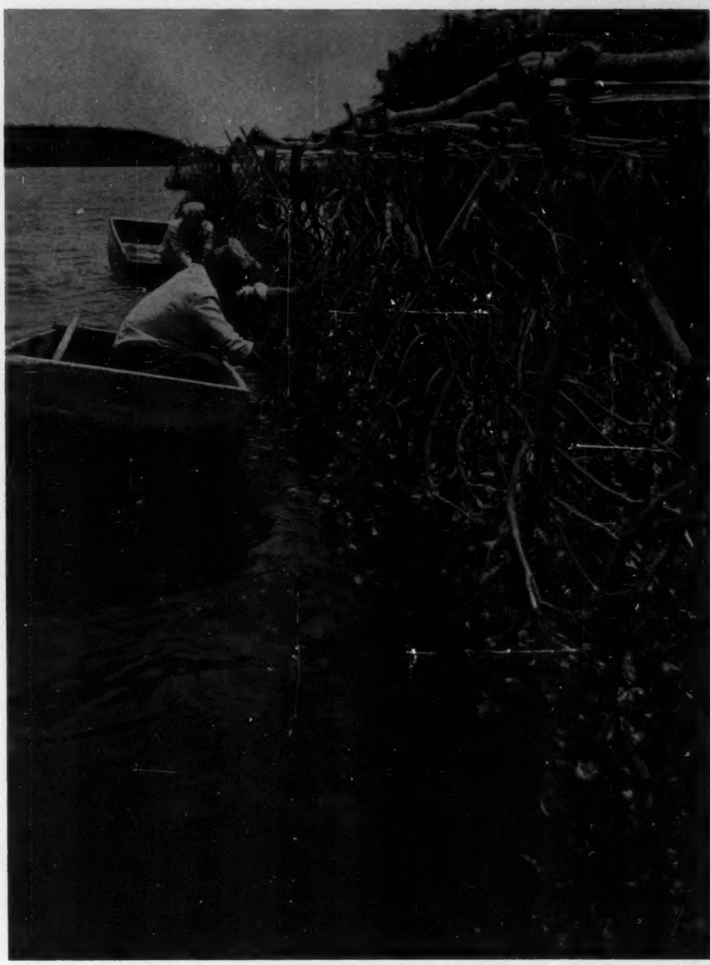

Figure 3.—Mangrove oyster culture system in Cuba.

Jamaica

In July 1977, a joint mangrove oyster culture project was set up by the International Development Research Center (IDRC) of Canada and the Government of Jamaica (through the Fisheries Division of the Ministry of Agriculture and the University of the West Indies' Department of Zoology) to determine its feasibility in arresting the loss in natural oyster populations to land reclamation, particularly in the Kingston Harbor area, and to ensure a constant or increased supply of oysters. After 4 years the culture system was considered viable so in 1980 an "Oyster Culture Unit" was set up within the Ministry of Agriculture to operate pilot farms and provide extension services[2].

[1]Frias-Lepoureau, J. A. Mariculture Section, Ministry of the Fishing Industry, Cuba. Personal commun., 1 October 1984.

[2]MooYoung, R. R. Inland Fisheries Project, Ministry of Agriculture, Jamaica. Personal commun., 8 November 1984.

The system adapted known oyster raft-culture methods to Jamaican conditions (Wade et al., 1981). Spat collectors are made of pieces of old car tires, cut into 8 × 8 cm squares and drilled in the center. These are strung together with monofilament line, (10-12 collectors per string), aged in seawater for 2 weeks before use, and then hung from bamboo and mangrove racks in the intertidal zone to collect spat. When the preferred density of about 10 oysters per collector has settled, the collectors are restrung on long monofilament plastic lines, spaced with 10 cm bamboo poles and tied to bamboo rafts. Flotation for the rafts is provided by 44-gallon oil drums painted with antirust paint, and anchored by nylon ropes tied to 80-pound concrete blocks. Market size of 7-8 cm is reached in 6 months. Only about 10 percent of production is suitable for marketing because of poaching, diseases, and fouling organisms, all major problems. In addition, some potential growout sites located near urban centers may give rise to health problems caused by pollution; therefore, the Jamaican government is considering depuration plants and strict marketing regulations (ADCP, 1983).

Oyster spat is presently collected at the pilot farm of the Oyster Culture Unit in Bowden, Port Morant. Growout is only carried out at this time in Port Antonio, where local fishermen built and have maintained growout rafts since January 1982. Growout was attempted at Falmouth, but was discontinued due to high coliform counts. Microbial studies to institute preventive measures are under way in a joint project between the University of the West Indies and the University of South Florida.

Belmont-Bluefields is a proposed growout site. There are plans to grow the oysters in baskets and trays, which produce single shells instead of clusters, and which have more appeal for tourists. There is a high demand for oysters from hotels and restaurants, and all present production is readily sold in Kingston. No reliable production figures are available but the quantities sold are reported to be small. Three Jamaican workers from the Project have recently completed overseas training at Dalhousie University in Canada through IDRC scholarships. Finally, an experimental oyster hatchery is being planned[3].

Mexico

In Mexico, commercial aquaculture activities involving oysters (and seven other groups of organisms which include shrimp and lobsters) are reserved exclusively for aquaculture cooperatives. Although the most successful oyster farming cooperatives are located along Mexico's Pacific coast (culturing a local species, *Crassostrea corteziensis*), experimental oyster culture in Mexico began in the lagoon of Tamiahua in 1957 (Conrad, 1985). American oysters are also raised, and its most important culture grounds are on Mexico's Gulf coast, in the lagoons of Pueblo Viejo, Tamiahua, Tampamochoc, Machona-Carmen, Macoacan and others in the States of Veracruz and Tabasco (Lizarraga, 1974).

Seed is commonly collected on collars of oyster shell cultch, although roof tiles and wire-mesh or plastic bags are also used. Spat collectors are placed in stockades, hung from traverse beams, and after 2-3 months (when the seed is 2-3 cm) they are moved for growout. Two basic systems are used. In one the collectors are placed on the bottom in areas consolidated with old oyster shells, and in the other, a suspension system is used with collectors strung on galvanized wire strings, separated by plastic tubing, and hung in stockades. Growout time to commercial size (about 8-10 cm) is between 8 and 14 months, and the reported yield from these areas averages 25 tons/ha (Haro et al., 1983; Lizarraga, 1974).

The potential for increased oyster production in the Gulf of Mexico is considerable, with over 100,000 ha having potential for utilizing intensive culture techniques (Haro et al., 1983). Current production is about 40,000 t/year, but a decline is predicted due to pollution in lagoons such as Tamiahua and others[4], where oil exploitation activities have resulted in destruction of natural beds (Conrad, 1985).

Venezuela

Experimental culture of the American oyster began in 1974 in the canals of Guariquen, in the Gulf of Paria. The Center for Fisheries Research of Cumana, under the Ministry of Agriculture and Livestock, beginning in 1974, carried out several studies on the biology and culture potential of the American oyster (unpubl.) which stimulated the creation of two commercial ventures in 1980. For spat collection and growout these operations used old tires cut in strips and hung from floating wooden rafts. In November 1980, there were 120 rafts: 100 rafts were 15 × 6 m with 420 strips each and 20 rafts were 15 × 14 m with 800 strips each. Commercial size, 8-12 cm, is reached in 1 year.

The marketed production in 1980, 1981, and 1982 was 170, 176 and 132 tons, respectively. The estimated production of a single operation in 1980 was about 1,000 t, most of which could not be marketed because the marketing channels were inadequate to handle production. Studies of the economic feasibility of smoking and canning oyster meats, possibly for export, have been made (Cervigon, 1983). However, in a recent visit to Venezuela, the senior author was informed that marketing difficulties had apparently proved insurmountable and that both commercial ventures would cease operations.

The mangrove oyster was also the subject of experimental and commercial culture in Venezuela. Experimental culture began in the early 1960's, and there were two commercial attempts, both using wild spat and floating rafts: One, in 1969, in the Gulf of Cariaco and the other in 1971 in la Restinga lagoon, Margarita Island. Both faced problems of spat settling, competition, and shell brittleness, and both failed due to marketing difficulties (Mandelli and Acuna, 1975; Cervigon, 1983).

Culture of rock mussels, *Perna perna*, began in 1960 in the Gulf of Cariaco in northeastern Venezuela (Fig. 4) using slightly modified Spanish raft-culture techniques (Iversen, 1966). Presently, there are two private ventures with 20 rafts and seven smaller ventures with a

[3]Sessing, J. Jamaican aquaculturist, P.O. Box 642, Kingston 8, Jamaica. Personal commun., April 1985.

[4]Orbe, A. Centro de Investigacion y Estudios Avanzados IPN, Unidad Merida, Merida, Yucatan, Mexico. Personal commun., 6 November 1984.

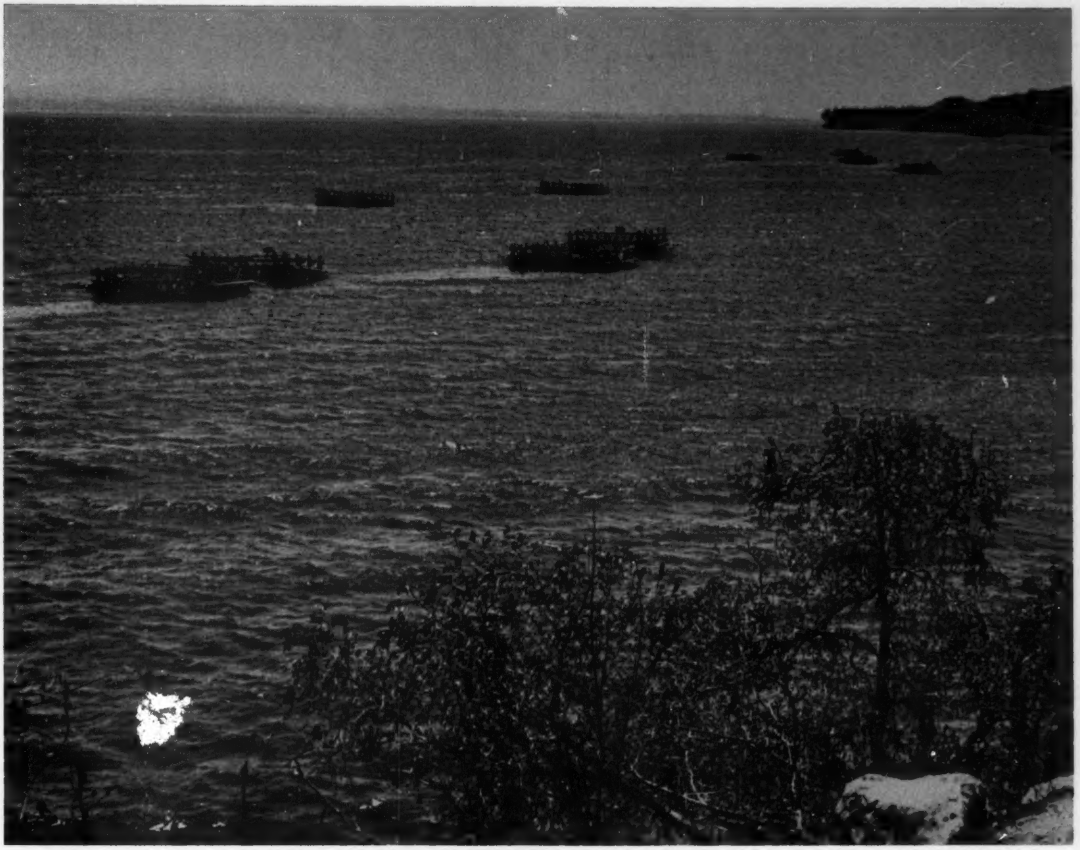

Figure 4.—Rock mussel rafts in Venezuela.

total of 45 rafts operated by fishermen's cooperatives. The latter have not produced any mussels in the last few years because of red tide problems in the area which, in August 1977, killed nine people who ate contaminated mussels.

Annual market production since 1972 has ranged from 42 to 650 t. In 1980, production was estimated at 650 to 920 t, but only 30 t were marketed due to red tide. In 1983, production was estimated at 182 t. This decrease is attributed to the replacing of wooden spat collectors by tire strips to which mussel spat reportedly cannot attach securely. Besides red-tide-related problems, commercially successful mussel culture in Venezuela faces marketing problems similar to that of oysters (Salaya et al., 1973; Mandelli and Acuna, 1975; Cervigon, 1983). Extensive research on the rearing of mussel larvae has been recently carried out at the Instituto Oceanografico of Universidad de Oriente in Cumana[5]. A project to set up a mussel depuration plant is being planned, and another project for a large-scale mussel farming operation was recently presented to the National Council for Scientific Research of Venezuela (CONICIT) and is presently being evaluated[6].

[5]Cervigon, F. Fundacion Cientifica Los Roques, Caracas, Venezuela. Personal commun., May 1985.

[6]Robaina, G. Universidad de Oriente, Boca de Rio, Isla de Margarita, Venezuela. Personal commun., December 1985.

Extensive Culture

The queen conch, *Strombus gigas*, is the only marine mollusk considered to be cultured extensively in the Caribbean. Increased demand for its meat, especially in U.S. markets, has resulted in overfishing and the decline of stocks, and has threatened its critical role as one of the most important subsistence-level fisheries of the area (Brownell and Stevely, 1981).

Concern over the decline of stocks led to extensive research on the mass-rearing of juveniles in hatcheries and using these juveniles to reestablish or replenish depleted natural populations. Such research was carried on since about 1980 in Bonaire, Puerto Rico, Los Ro-

ques Archipelago in Venezuela, Quintana Roo in Mexico, Turks and Caicos, Miami, and the Berry Islands in the Bahamas (Iversen and Jory, 1985).

Preliminary results of many of these research programs were presented in a Conch Mariculture Session at the 35th Annual Gulf and Caribbean Fisheries Institute in Nassau, Bahamas, in November 1982. What has happened since then? The projects at the University of Miami, Los Roques and the Berry Islands have ended due to lack of financial support. The project in Puerto Rico might not receive further funding[7]. However, there is also encouraging news. The Bonaire hatchery reported rearing and releasing 750,000 juveniles off Bonaire in 1984 in deep waters where they will not be easily accessible to fishermen[8]. This may be an example of technological success, but does not imply economic feasibility. A hatchery is being set up at the Hydrolab site at Salt River on St. Croix, U.S. Virgin Islands, mainly to obtain animals for further research[9]. And construction of a hatchery is about to begin on the island of Martinique, French West Indies[10].

The senior author recently visited the Puerto Morelos hatchery in Quintana Roo, Mexico, and was informed that it is preparing for its first field release of hatchery-reared juveniles. Finally, in 1984 Trade Wind Industries, Inc.[11], constructed and started operating the first commercial queen conch hatchery on the island of Providenciales, Turks and Caicos. During the 1984 spawning season, 20 larviculture tanks were in operation, and the juvenile conchs produced were stocked in protective cages near the hatchery. The company reportedly has also acquired sea-bottom leases to grow conch to commercial size[12].

The release size for hatchery-reared conch discussed, and recommended and/or used so far varies from 2 cm (Siddall, 1983), to 5 cm (Creswell, 1984) to 12-15 cm (Jory and Iversen, 1983; Woon, 1983). The release size can have important consequences on the rate of survival to market size. There is good scientific evidence that natural mortality is greater for smaller individuals, and hatchery-reared mollusks are no exception (Jory et al., 1984), including queen conch (Appeldoorn and Ballantine, 1983; Jory and Iversen, 1983) as well as other mollusks such as abalone[13]. Recent large-scale releases of small (2-5 cm) hatchery-reared conchs in Bonaire, Mexico, Venezuela, and St. Croix should provide an indication of the optimum release size.

Pilot Projects and Research Activities

Bahamas

Molluscan mariculture has been attempted at three locations in the Bahamas. In the middle 1970's a private company conducted a pilot experiment with imported American oysters. In a pond dredged out for a dock project in Rudder Cut Cay, Exuma, the water was fertilized and imported oyster spat was placed in rafts. The project was promptly abandoned due to very slow growth rates.

The second study, growing oysters and clams in rafts by the Wallace Groves Aquaculture Foundation of Freeport, produced discouraging results. The third study is by Worldwide Protein Bahamas Ltd., using imported spat of American and European oysters and hard clams, *Mercenaria mercenaria*, grown in discharge canals from company shrimp ponds on Long Island. Preliminary results indicate that fouling by algae and particulate matter hinder production. Water temperatures were too high for European oysters and the species may be abandoned, but growout of American oysters and hard clams continues. In addition, the company recently obtained permission from Bahamian authorities to import Manila clams, *Tapes japonicus*, from the Philippines, for growout trials[14].

Turks and Caicos

The Smithsonian Institution's Marine Systems Laboratory has recently sought to determine the culture potential of the topshell or magpie shell, *Cittarium pica*. Its life cycle has been closed (Heslinga and Hillmann, 1981), and preliminary results indicate that juveniles placed in floating cages can reach market size in 12-18 months. Similar research has also been carried out in the Dominican Republic, Antigua, and St. Vincent[15]. The Mariculture Team of the Marine Systems Laboratory visited the island of St. Lucia where they demonstrated topshell culture methods; these appeared to be easily adapted to local conditions, and the feasibility of establishing a pilot project was indicated[16].

Topshells are widely consumed in the Caribbean; the species has been overfished in many areas and several nations are contemplating plans to regulate its fisheries. Mariculture may be a viable option to increase production since topshells appear to fulfill many of the criteria for commercial culture.

St. Lucia

In 1983 a joint "Experimental Oyster Project" was started on St. Lucia between a local yacht charter company and the Fisheries Management Unit of the Ministry of Agriculture, Lands, Fisheries, and Cooperatives. Imported Japanese oyster, *Crassostrea gigas*, spat were placed in bamboo and plastic mesh rafts at two sites. Unfortunately, the rafts at one site were destroyed but there are

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[7]Appeldorn, R. Department of Marine Sciences, University of Puerto Rico, Puerto Rico. Personal commun., October 1984.

[8]Hensen, R. Department of Agriculture and Fisheries, Bonaire. Personal commun., October 1984.

[9]Coulston, M. L. Hydrolab Project West Indies Laboratory, Fairleigh Dickinson University, St. Croix. Personal commun., 22 October 1984.

[10]Bazin, P. Association pour le Development de l'Aquaculture a la Martinique, Martinique. Personal commun., September 1984.

[11]Mention of trade names or commercial firms does not imply endorsement by the National Marine Fisheries Service, NOAA.

[12]Creswell, L. Center for Marine Biotechnology, Harbor Branch Institution, Inc., Florida. Personal commun., November 1984.

[13]Haaker, P. California Department of Fish and Game. Personal commun., October 1983.

[14]Higgs, C. Ministry of Agriculture, Fisheries and Local Government, Nassau, Bahamas. Personal commun., October 1984.

[15]Bernard, W. L. Marine Systems Laboratory, Smithsonian Institution, Washington, D.C. Personal commun., October 1985.

[16]Walters, H. D. Ministry of Agriculture, Lands, Fisheries, and Cooperatives, Castries, St. Lucia. Personal commun., 5 October 1984.

plans for a second attempt. In addition, several local private concerns have contacted the Fisheries Management Unit for advice regarding oyster culture[16].

Panama

Between January and December 1979, two pilot studies were conducted to determine culture potential of the mangrove oyster. Two experimental farms were located in the Archipelago de Bocas del Toro, using the Cuban culture system described earlier in this paper. Preliminary results were encouraging but the project was not scaled-up to a commercial level[17]. University of Panama and University of Delaware scientists are jointly experimenting with commercially important bivalves with encouraging results at the University of Panama's Centro de Ciencias del Mar y Limnologia laboratory on Panama's Pacific coast[18].

Colombia

Studies on mangrove oyster biology, preparatory to culture, have been carried out at the Cienaga Grande de Santa Marta and in the Gulf of Uraba on the Caribbean coast of Colombia. Research has concentrated on basic biological aspects of the oysters and testing for the best methods of spat collection and growout. Results are very encouraging; it may be possible to raise oysters in closed suspended baskets to commercial size (6-8 cm) in about 7 months. Bottom culturing methods are not suitable in the Gulf of Uraba due to the heavy sedimentation coming from the Rio Atrato (Wedler, 1980; Aguilera, 1984). No plans for commercial scale-up were mentioned.

St. Kitts and Nevis

In 1981 the Government of St. Kitts and Nevis and the IDRC tried unsuccessfully to establish a pilot project to culture mussels. The project failed because no suitable local species of mussel could be found. In 1983 the project was redesigned into a Conch Management Program with a "red algae, *Gracilaria* spp., Research Project" as a subcomponent, which continues[19].

Nicaragua

In 1976, an oyster culture pilot study was carried out with assistance from Japanese scientists, using strung scallop shells separated by PVC spacers and hung from mangrove structures. Spat was successfully collected and grown during the dry season (May-December) but failed during the rainy season due to depressed salinities and high sedimentation in the estuarine site. Oysters grew well up to 81 mm, but mortalities were more than 80 percent. Because most of the Nicaraguan coastline where oysters can be raised has similar estuarine conditions, government officials are not inclined to conduct further oyster culture experiments[20].

Puerto Rico

Experiments to determine the commercial feasibility of mangrove oyster culture started in December 1972, with the joint support of the Puerto Rico Department of Agriculture and the U.S. National Marine Fisheries Service. These experiments consisted of monitoring growth of collected spat in bags, with frames made of concrete-coated plywood and plastic sheeting suspended from 3 × 4 m rafts. Oysters reportedly reached market size in 2 months (Watters and Prinslow, 1975). No commercial oyster culture presently exists in Puerto Rico. The Commonwealth Government encourages such nondestructive uses of its coastal lagoons which are coming under increasing development pressure[21].

U.S. Virgin Islands

Since May 1972, the St. Croix Artificial Upwelling Project on the north shore of the island produced phytoplankton by pumping nutrient-rich seawater from 870 m depth into 100 m^2 ponds. This was used to feed oysters, clams, and scallops which grew adequately. A pilot-scale operation was carried out between October 1976 and October 1978 in which Manila clams produced in the Project Hatchery were successfully grown to determine yields and production costs. Very encouraging results were also obtained culturing brine shrimp (Roels et al., 1979). The Project apparently developed into The Maritek Corporation in 1980 (Seafood Business Report, 1984), and is presently engaged in penaeid shrimp culture in the Bahamas[22].

Other Candidates

Caribbean Species

Milk Conch

The milk conch, *Strombus costatus*, although considerably smaller than the queen conch, is nevertheless of commercial value. Its biology has been studied and it has been reared for possible use in the marine aquarium trade and for extensive mariculture. Hatchery techniques, predation problems, and outlook are very similar to those for the queen conch (Appeldoorn and Ballantine, 1983).

Great White Lucine and Gaudy Asaphis

In many Caribbean areas, low primary productivity generally precludes culturing suspension-feeding mollusks. Recent research has shown two clam species, the great white lucine, *Codakia orbicularis*, and the gaudy asaphis, *Asaphis deflorata*, to have possible chemoautotrophic capabilities through a symbiotic relationship with sulphur-fixing bacteria within their gill tissues; hence, they have been suggested as viable mariculture candidates. Both species have been reared in the laboratory, and chemical analyses have shown that the

[17]Arosemena, D. H. Departamento de Direccion de Recursos Marinos, Panama. Personal commun., 28 September 1984.

[18]D'Croz, L., and J. R. Villalaz. Centro de Ciencias del Mar y Limnologia, Facultad de Ciencias Naturales y Farmacia, Universidad de Panama. Personal commun., 29 October 1984.

[19]Wilkins, R. Department of Agriculture, St. Kitts and Nevis. Personal commun., 25 September 1984.

[20]Martinez Casco, S. Centro de Investigaciones Pesqueras, Instituto Nicaraguense de la Pesca. Personal commun., 4 October 1984.

[21]Torres, F. Corporation for the Development and Administration of the Marine Resources, Puerto Rico. Personal commun., 7 November 1984.

[22]Higgs, C. Ministry of Agriculture, Fisheries and Local Government, Nassau, Bahamas. Personal commun., July 1984.

great white lucine is relatively high in protein, carbohydrates, and calories but low in cholesterol compared with other clam species (Berg and Alatalo, 1982). It has also been speculated that industrial sulfide wastes may be adapted to a mariculture system involving these clams (Berg and Alatalo, 1984). No pilot or commercial projects to rear these clams are planned[23].

Cephalopods

Many cephalopod species are important research subjects in neuroscience, environmental toxicology, learning behavior, and other areas. The highly developed giant axon of squids, for example, is used in numerous models of visual experimentation (Hanlon and Forsythe, In press). In addition, fisheries biologists have recently begun using cultured cephalopods for life-cycle analyses (Hanlon, In press). The advantages of laboratory-cultured cephalopods to the researcher include the consistent availability of experimental animals of known species, age, sex, and environmental background (Hanlon and Forsythe, In press). In the Western Atlantic, cephalopods are presently being cultured on an experimental scale at the Marine Biomedical Institute of the University of Texas Medical Branch, Galveston, Tex.[24], and at the Centro de Investigaciones Cientificas de la Universidad de Oriente, on Margarita Island off northeastern Venezuela (Robaina, 1983).

Roger Hanlon of the Texas Marine Biomedical Institute reports[24] that the life cycles of several *Octopus* and *Loligo* species have been closed, and extensive information pertinent to their potential commercial mariculture has been accumulated. He further reports receiving requests from people interested in culturing cephalopods commercially in the southern Caribbean.

The only known commercial culture operation of cephalopods is in Japan, where *Octopus vulgaris* is reared; production in recent years was about 50 t annually (Boletzky and Hanlon, 1983). However, "the outlook for future commercial culture of cephalopods is unpredictable, because it is predominantly an economic consideration. When and if the capture fishery cannot meet the market demand, culture will receive emphasis" (Hanlon, In press). Finally, cephalopods may have much potential in the aquarium trade, because of the spectacular color changes of many species and because they can be easily maintained in aquariums (Hanlon, In press).

Scallops

Scallops of the family Pectinidae are the basis of several important commercial fisheries around the world. Commercial scallop farming in Japan has been very successful, and scientists elsewhere are trying to adapt Japanese techniques to their own countries (Wood, 1978). Pilot research continues worldwide, and in Latin America, Peru (Wolff, 1984), and Mexico (Kimbrough, 1983) have recently reported commercial culture operations. Those, however, are on the Pacific coast; no pilot- or commercial-scale scallop culture project is known in the Caribbean. Research on induced reproduction and larval rearing is being carried on in Venezuela[25]. Berg (1984) recently suggested scallop culture as having potential in Bermuda.

Pearl Oysters

Pearl oysters have been successfully cultured for many years in Japan, Republic of Korea, China, Australia, Indonesia, the Philippines, and other countries, and the techniques are well known. Berg (1984), in reviewing the culture potential of Bermudian bivalves, mentioned that there appears to be no reason why these techniques could not be successfully applied to Atlantic pearl oysters, *Pinctada* spp. On Mexico's Pacific coast the pearl oyster, *P. mazatlanica*, has been experimentally cultured[26]. No information is available on present or recent research on pearl oyster culture in the Caribbean, although in Venezuela aspects of its biology have been studied to some extent (Martinez, 1971), and a research proposal is currently being evaluated[27].

Pen Shells

The culture potential of pen shells, *Pinna carnea* and *Atrina rigida*, was also reviewed by Berg (1984), who concluded that they seem to have poor potential because of the possibly long planktonic development which would make larval rearing difficult. He also mentioned that they may be suitable as an additional species in a polyculture system, since they seem to invest little energy developing viscera and shell and therefore might grow very fast. Pen shells are very valuable in several Caribbean countries, and in Mexico, where they command higher prices than shrimp and as high as abalone (about U.S.$10.00/kg as of early 1985)[28]. A shellfish hatchery to produce larvae of commercially important bivalves, including several species of oysters, clams, scallops, and pen shells, recently started operating in Bahia Kino, in the Gulf of California (O'Sullivan, 1984). No commercial or research projects are known in the Caribbean.

Exotic Species

Green Mussels

A species from the Indo-Pacific, the green mussel, *Perna viridis*, is considered to be a good candidate for introduction into the Caribbean. Presently there are over 5,000 ha under its culture in Thailand and the Philippines. Research at the Harbor Branch Institution in Florida has shown considerable potential for this species' culture in localized Caribbean areas where primary productivity is sufficient to support filter-feeding bivalves[29].

Giant Clams

Species of giant clams, *Tridacna* spp., are being intensively studied at various institutions in the Philippines, Australia, Micronesia, and California for possible commercial culture. These

[23]Berg, C. J. Woods Hole Oceanographic Institution. Personal commun., 7 November 1984.
[24]R. Hanlon, Marine Biomedical Institute, Texas. Personal commun., 5 November 1984.

[25]Padron, M. Universidad de Oriente, Boca de Rio, Isla de Margarita, Venezuela. Personal commun., 5 December 1985.
[26]Diaz, G. J. J. 1969. Cultivo experimental de madreperla, *Pinctada mazatlanica*, en la Bahia de La Paz, Baja Calif., Mex., (mimeogr.) 12 p.

[27]Robaina, G. Universidad de Oriente, Boca de Rio, Isla de Margarita, Venezuela. Personal commun., 4 December 1985.
[28]Reyes, C. Instituto Tecnologico y de Estudios Superiores de Monterrey, Guaymas, Sonora, Mex. Personal commun., March 1985.
[29]Creswell, L. Center for Marine Biotechnology, Harbor Branch Institution, Fl. Personal commun., November 1984.

clams have a thin layer of tissue in their mantle where zooxanthellae live and provide food (Munro and Heslinga, 1983). This aspect of their biology is unique and actually is a strong plus for the species' introduction to the Caribbean, particularly in areas of low productivity that cannot support filter-feeding bivalves such as oysters or mussels. Cultured tridacnids from Palau may soon be introduced to the island of Guadaloupe, pending approval of import permits[30]. However, as with any other exotic species, the possible ecological consequences of introducing any new species into a new environment must first be carefully considered, as is strongly urged by Munro and Heslinga (1983).

Discussion and Conclusions

Molluscan mariculture is nonexistent in several Caribbean countries; in a few it is at an experimental or incipient stage of development while only a handful of commercial molluscan culture operations presently exist anywhere in the area. Three species of bivalves (American and mangrove oysters and rock mussels) are raised in semi-intensive facilities; one gastropod, the queen conch, is raised in extensive culture (mass-reared in hatcheries and released to augment natural populations).

Techniques for oyster and mussel culture are very similar, involving wild spat collection on different substrates (i.e., from mangrove branches to synthetic ropes) and growout with the collectors suspended from floating rafts or wooden stockades. These techniques have proven successful in some Caribbean countries and have potential in several others. Queen conch culture involves mass-rearing juveniles in hatcheries and field growout to commercial size; the first has had limited success so far while the second remains unproven.

Introduction of exotic molluscan species into the Caribbean must be carefully considered. Several native species, particularly filter-feeding bivalves, appear suitable and should be exhaustively studied before considering any introduction. An exception may be that of exotic species with phototrophic capabilities, such as giant clams, which may be suitable for introduction in those areas where the naturally low primary productivity precludes the culture of filter-feeding species. However, much care should be exercised if these or any other exotic species is introduced into the Caribbean, and guidelines such as those recommended by the International Council for the Exploration of the Sea should be followed (ICES, 1972).

Several problems still hamper Caribbean molluscan culture. These include insufficient biological information on potential candidate species, dependency on wild spat, lack of economic information, few trained technicians, inadequate marketing channels, low primary productivity in many areas, and pollution and public health considerations.

The FAO Species Identification Sheets for Fishery Purposes of the Western Central Atlantic (Fischer, 1978) list 37 bivalves and 24 gastropods which are large, edible, and common enough to serve as human food. Several of these species of oysters, clams, scallops, arks, mussels, and pen shells, as well as others not included in the FAO sheets, may meet the criteria for culture candidates proposed by Bardach et al. (1972) and Webber and Riordan (1975).

However, adequate biological information on which to judge the feasibility of culture projects for many species is lacking, particularly concerning reproductive aspects (spawning season, larval stage requirements) and growth rates and factors which affect it. Research in progress at several Caribbean institutions will help alleviate this. However, economic support for research sometimes may end prematurely, as in the case of the queen conch, whose biology and culture potential (including hatchery techniques) was intensively investigated at several institutions for a few years, until funding was discontinued. UNDP/FAO has advocated establishment of a Caribbean Regional Aquaculture Center, which has also been strongly supported by countries in the region and may be approved and implemented in the near future[31].

To depend on natural spat settlement as a source of seed for commercial growout is generally not advisable because of the wide fluctuations in spat abundance and settlement due to biotic and abiotic factors. Cuba, for example, has reported such problems for their oyster culture operations, and is investigating controlled reproduction and oyster larval maintenance as well as construction of a hatchery. Other countries such as Mexico, Jamaica, Panama, and Venezuela are operating or planning hatcheries and/or are involved in active research for this purpose.

Economic problems also hamper development of Caribbean molluscan culture (as well as culture of most other marine species), particularly the distribution channels and availability of the products. Acceptability of seafood is not a problem: Most Caribbean islands and countries bordering the Caribbean have high rates of seafood consumption (>20 g/person per day), and in some of these countries fish constitutes almost 20 percent of the total protein source (Olsen et al., 1984). Adequate distribution channels and product availability problems must be viewed in terms of the added technological and economic burden involved in processing and marketing highly perishable products in places where refrigeration may be unavailable or inadequate (May, 1978). That inadequate marketing channels are a problem today is exemplified by the Venezuelan oyster culture operations discussed previously.

Another problem is pollution and related public health considerations. Since the Caribbean is generally a developing region with relatively modest industrialization and urbanization, water pollution from land-produced wastes has not reached the alarming levels of more industrialized regions. However, there are localized areas where marine pollution from industrial, domestic, and agricultural wastes, and from oil production and transport, is a problem (Rodriguez, 1981), and this is likely to become a problem in other areas as industrialization and urbanization occur.

Estuarine areas are particularly affected by pollution and urban development. Besides being highly productive nursery grounds for many commercially important animals, clean estuaries are

[30]Heslinga, G. Micronesian Mariculture Demonstration Center, Palau. Personal commun., February 1985.

[31]Choudhury, P. C. Fishery Resources and Environment Division, FAO, Rome. Personal commun., 28 September 1984.

also needed for molluscan culture. Public health aspects of pollution must be especially considered because the occurrence of human viruses in mollusks from waters lightly to moderately polluted is well documented (Vaughn and Landry, 1984) and because information on the extent of pollution in the Caribbean (i.e., from sewage) is very limited (Rodriguez, 1981).

Finally, the harvesting of cultured mollusks may often have to be restricted owing either to periodic red tide outbreaks, as in the case of the Venezuelan mussel culture operations discussed, or to ciguatera poisoning, which may occur in populations of topshells of certain areas (Olsen et al., 1984).

In conclusion, molluscan mariculture in the Caribbean has a long way to go to partially augment catches from traditional capture fisheries. It is doubtful that it can soon achieve the production per unit area obtained in other parts of the world because it is still in its infancy and many of the problems remain unresolved. However, current and planned research are encouraging.

Acknowledgments

This report is based on a search of the available literature and on personal communications with researchers, fisheries officers, and administrators involved in or knowledgeable about aquaculture activities throughout the Caribbean, whose contributions we thankfully acknowledge. A shortened version of this manuscript was presented at the November 1984 MEXUS-GULF IV and Gulf and Caribbean Fisheries Institute 37th Annual Meeting in Cancun, Mexico.

Literature Cited

ADCP. 1983. A policy for development of aquaculture in Jamaica. Report of a Government of Jamaica/ADCP study group, 11 January-24 February 1983. UNDP/FAO (Rome) ADCP/MR/83/22:115.

Aguilera, A. 1984. Proyecto ostricultura. IV Etapa, Enero-Dic. 1983. INVEMAR-COLCIENCIAS-CIID. Santa Marta, Colombia, 37 p.

Appeldoorn, R. S., and D. L. Ballantine. 1983. Field release of cultured queen conch in Puerto Rico. *In* J. B. Higman (editor), Proc. 35th Annu. Gulf Caribb. Fish. Inst., Nassau, Bahamas, Nov. 1982, p. 89-98.

Bardach, J. E., J. H. Ryther, and W. O. McLarney. 1972. Aquaculture—The farming and husbandry of freshwater and marine organisms. Wiley-Interscience, N.Y., 868 p.

Berg, C. J. 1984. Aquaculture potential of Bermudian bivalve molluscs. *In* T. D. Sleeter (editor), Assessment of the potential for aquaculture in Bermuda, p. 77-89. Bermuda Biol. Stn., Ferry Reach, St. George's.

_________, and P. Alatalo. 1982. Mariculture potential of shallow-water Bahamian bivalves. J. World Maricult. Soc. 13:294-300.

_________, and _________. 1984, Potential of chemosynthesis in molluscan mariculture. Aquaculture 39:165-179.

Boletzky, S., and R. T. Hanlon. 1983. A review of the laboratory maintenance, rearing, and culture of cephalopod molluscs. Mem. Natl. Mus. Victoria 44:147-187.

Brownell, W. N., and J. M. Stevely. 1981. The biology, fisheries, and management of the queen conch, *Strombus gigas*. Mar. Fish. Rev. 43(7): 1-12.

Cervigon, F. (editor). 1983. La Acuicultura en Venezuela. Estado Actual y Perspectivas. Editorial Arte, Caracas, 121 p.

Conrad, J. 1985. Mexico's cooperative oyster and shrimp farms. Aquaculture Magazine, September/October 1985:46-49.

Creswell, L. 1984. Conch mariculture in the Caribbean region and its potential for Bermuda. *In* T. D. Sleeter (editor), Assessment of the potential for aquaculture in Bermuda, p. 133-141. Bermuda Biol. Stn., Ferry Reach, St. George's.

Fay, R. C. 1971. Marine organisms in the research laboratory. Sea Scope 2(2):1, 7-8.

Fischer, W. 1978. FAO species identification sheets for fishery purposes. West. Cent. Atl. Vol. 6., FAO, Rome.

Hanlon, R. T. In press. Mariculture. *In* P. R. Boyle (editor), Cephalopod life cycles, Vol. 2. Academic Press, N.Y.

_________, and J. W. Forsythe. In press. Advances in the laboratory culture of octopuses for biomedical research. Laboratory Animal Science.

Haro, B. H., E. P. Nunez, A. F. Mattas, and M. A. Landin. 1983. The development and perspective of oyster culture in Mexico. *In* K. K. Chew (editor), Proc. North Am. Oyster Workshop, p. 64-69. World Maricult. Soc. Spec. Publ. 1.

Heslinga, G. A., and A. Hillman. 1981. Hatchery culture of the commercial top snail, *Trochus niloticus*, in Palau, Caroline Islands. Aquaculture 22(1981):35-43.

ICES, 1972. Report of the working group on introduction of nonindigenous marine organisms. Int. Counc. Explor. Sea Coop. Res. Rep. 32, 59 p.

Iversen, E. S. 1966. New float brings hope to mussel farmers. Fish. News Intl. 5(10):49.

_________, and D. E. Jory. 1985. Queen conch at the crossroads. Sea Front. 31(3):150-159.

Jory, D. E., and E. S. Iversen. 1983. Conch predators: Not a roadblock to mariculture. *In* J. B. Higman (editor), Proc. 35th Annu. Gulf Caribb. Fish. Inst., Nassau, Bahamas, Nov. 1982, p. 108-111.

_________, M. R. Carriker, and E. S. Iversen. 1984. Preventing predation in molluscan mariculture: An overview. J. World Maricult. Soc. 15:421-432.

Kimbrough, A. 1983. Commercial mariculture of a bay scallop, *Argopecten circularis* in the Ensenada of La Paz, Baja California Sur, Mexico. J. Shellfish Res. (Abstr.) 3(1):114.

Lizarraga, M. 1974. Tecnicas aplicadas en el cultivo de moluscos en America Latina. Simposio FAO/CARPAS sobre acuicultura en America Latina. Montevideo, Uruguay, 26 Noviembre-2 Diciembre 1974. FAO/CARPAS/6/74/SR 8, 10 p.

Mandelli, E. F., and A. Acuna. 1975. The culture of the mussel, *Perna perna*, and the oyster, *Crassostrea rhizophorae*, in Venezuela. Mar. Fish. Rev. 37(1):15-18.

Martinez, E. R. 1971. Estado actual de la biologia y cultivos de moluscos comestibles en Venezuela. Coloquio sobre Investigaciones Y Recursos del Mar Caribe y Regiones Adyacentes. FAO Fish. Rep. 71.2:173-181.

May, R. C. 1978. Marine food production: Problems and prospects for Latin America. Rev. Biol. Trop. 26(Suppl.1):167-189.

Morse, D. E., K. K. Chew, and R. Mann (editors). 1984. Recent innovations in cultivation of Pacific mollusks. Proc. Int. Symp. La Jolla, Calif., December 1982, Aquaculture 1984:404.

Munro, J. L., and G. A. Heslinga. 1983. Prospects for the cultivation of giant clams. *In* J. B. Higman (editor), Proc. 35th Annu. Gulf Caribb. Fish. Inst., Nassau, Bahamas, Nov. 1982, p. 122-134.

Nikolic, M., A. Bosch, and S. Alfonso. 1976. A system for farming the mangrove oyster, *Crassostrea rhizophorae*. Aquaculture 9(1976):1-18.

Olsen, D. A., D. W. Nellis, and R. S. Wood. 1984. Ciguatera in the eastern Caribbean. Mar. Fish. Rev. 46(1):13-18.

O'Sullivan, D. 1984. Giant shellfish hatchery begins production in Mexico. ICLARM Newsl. 7(3):21-22.

Robaina, G. O. 1983. Algunos aspectos sobre el cultivo de los moluscos cefalopodos octopodos. Revista Latinoamericana de Acuicultura 16: 29-34.

Rodriguez, A. 1981. Marine and coastal environmental stress in the wider Caribbean region. Ambio 10(6):283-294.

Roels, O. A., J. B. Sunderlin, and S. Laurence. 1979. Bivalve molluscan culture in an artificial upwelling system. Proc. World Maricult. Soc. 10:122-138.

Salaya, J. J., I. Beauperthuy, and J. Martinez. 1973. Estudio sobre la biologia, pesqueria y cultivo del mejillon, *Perna perna*, en Venezuela. Oficina Nacional de Pesca, Ministerio de Agricultura y Cria, Republica de Venezuela. Informe Tecnico 62, 53 p.

Seafood Business Report. 1984. Maritek to harvest shrimp. Spring 1984, p. 98.

Siddall, S. E. 1983. Biological and economic outlook for hatchery production of juvenile queen conch. *In* J. B. Higman (editor), Proc. 35th Annu. Gulf Caribb. Fish. Inst., Nassau, Bahamas, Nov. 1982, p. 46-52.

Vaughn, J. M., and E. F. Landry. 1984. Public health considerations associated with molluscan aquaculture systems: Human viruses. Aquaculture 39(1984):299-315.

Wade, B., R. Brown, C. Hanson, L. Alexander, R. Hubbard, and B. Lopez. 1981. The development of a low-technology oyster culture industry in Jamaica. *In* J. B. Higman (editor), Proc. 33rd Annu. Gulf Caribb. Fish. Inst., San Jose, Costa Rica, Nov. 1980, p. 6-18.

Watters, K. W., and T. E. Prinslow. 1975. Culture of the mangrove oyster, *Crassostrea rhizophorae*, in Puerto Rico. Proc. World Maricult. Soc. 6:221-233.

Webber, H. H., and P. F. Riordan. 1975. Criteria for candidate species for aquaculture. Proc. World Maricult. Soc. 6:389-406.

Wedler, E. 1980. Experimental spat collecting and growing of the oyster, *Crassostrea rhizophorae* Guilding, in the Cienaga Grande de Santa Marta, Colombia. Aquaculture 21:251-259.

Wolff, M. 1984. Early setback for scallop culture in Peru. ICLARM Newsl. 7(3):19-20.

Wood, M. (editor). 1978. Cultivation experiments help predict future stock levels. World Fish. 27(12):68.

Woon, G. L. 1983. Preliminary algal preference studies and observations of conchs, *Strombus gigas* and *S. costatus*, held in high densities. J. World Maricult. Soc. 14:162-163.

A Synopsis of the Tortugas Pink Shrimp, *Penaeus duorarum*, Fishery, 1981-84, and the Impact of the Tortugas Sanctuary

EDWARD F. KLIMA and FRANK J. PATELLA

ABSTRACT—Trawling for pink shrimp, Penaeus duorarum, *in the Tortugas Sanctuary off south Florida was prohibited from 15 May 1981 through 15 April 1983. A small portion of the sanctuary, the "toe of the boot" area, was opened to trawling from April 1983 until 15 August 1984, when it was again closed to trawling. This paper describes the impacts of the closure, opening, and subsequent closure of the "toe of the boot" area on shrimp trawling.*

Opening the toe area seemed to adversely affect the shrimp catch on the grounds, but the subsequent closure in August 1984 provided a bonanza catch during winter 1984. The Tortugas fishery shrimp yield is based upon the recruitment of the fishing effort expended on small shrimp in the sanctuary and/or toe of the boot area. The 1981 and 1982 recruitment was very poor, while the spring recruitment in 1983 and 1984 was good. The 1983 recruitment was quickly caught by the fleet fishing within the toe area, whereas the 1984 recruitment was saved from heavy exploitation by prohibiting trawling in the toe area. We concluded that fishing in the toe area has a negative impact on the overall shrimp yield on the Tortugas Grounds.

Introduction

The Gulf of Mexico Shrimp Fishery Management Plan established an area commonly known as the Tortugas Shrimp Sanctuary off south Florida (Fig. 1) and prohibited all trawling activity within that area between 15 May 1981 and 15 April 1983 (GMFMC, 1980). This regulation was founded on scientific data indicating that the sanctuary is a nursery area for the Tortugas stocks of pink shrimp, *Penaeus duorarum*, and that recruitment to the offshore fishery is dependent on the sanctuary. Lindner (1965) and Berry (1970), utilizing growth and mortality data, indicated that the yield of pink shrimp would be greater if harvest was delayed until shrimp were larger than the minimum legal size (69 count[1]) for landing shrimp in Florida.

Therefore, the concept of the Gulf of Mexico Fishery Management Council in reestablishing the sanctuary was to protect small, undersized shrimp from fishing. Furthermore, it was assumed that the distribution of small shrimp was confined mainly inside the sanctuary line and that shrimp outside the line were of legal size or larger. Thus, the establishment of a permanent sanctuary would result in an increase in annual yield of about 1 million pounds (GMFMC, 1980). A small portion of the sanctuary, the "toe of the boot" area was opened to trawling from April 1983 until 15 August 1984 to determine whether catch would increase and to determine the impact on shrimp yield, and trawling was prohibited in the permanent sanctuary thereafter.

This paper reviews the characteristics of the Tortugas fishery from the closure in May 1981 through December 1984. Also, catch, effort, size composition of the landings, and catch per unit effort (CPUE) are compared with the historical data from 1960 to 1979. We determined whether these characteristics were affected by the regulations or lack of regulations for May 1981 through December 1984.

[1]The number of shrimp without heads that constitutes 1 pound.

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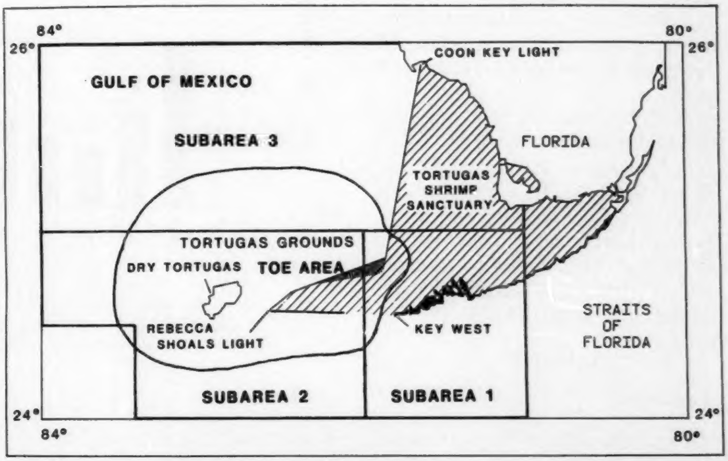

Figure 1.—The Dry Tortugas fishing grounds and statistical subareas.

Materials and Methods: Fishery Statistics

Detailed catch statistics describing the U.S. Gulf of Mexico shrimp fishery since 1956 are available, and the procedures used to collect them have been described by Klima (1980). The statistics compiled by the Southeast Fisheries Center (SEFC), Fishery Information Management Division (FIMD), were used to determine the effects of the Tortugas Shrimp Sanctuary.

Catch and effort statistics were grouped and analyzed by biological years (May-April) for ease of comparing the historical data with the period May 1981-December 1984. The statistics consisted of catch by statistical subarea (Fig. 1), fishing effort (in 24 hours of fishing time expressed as days fished), and size composition of the catch in eight size groupings. Locations and amount of fishing effort expended in 24 hours were obtained by interviewing vessel captains at the termination of their trips. All catch data were recorded as pounds of shrimp heads-off by species and size category, by statistical subarea, depth zone, and month.

Size composition of the reported catches was examined in units of pounds caught in eight "count" or size categories representing number of shrimp per pound, heads-off (<15, 15-20, 21-25, 26-30, 31-40, 41-50, 51-67, and ≥68). The weighted average number of shrimp per pound was calculated by multiplying the pounds landed in each of the size categories by the respective size grouping.

Catch and effort data from 1960 to the present are on file at the SEFC, FIMD office and are available for inspection. Ernest Snell (SEFC, FIMD) has provided specific information on Tortugas shrimp fishery fleet activities, changes in the fleet, number of trips, discards, and specifics of catch and effort for the fishing area during 1981-84.

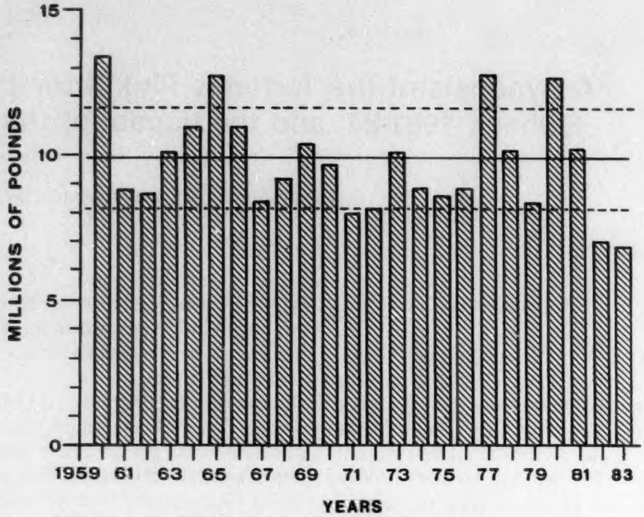

Figure 2.—Annual pink shrimp landings from the Tortugas grounds (SS 1-3) by biological years, 1960-83 (solid line is the mean; each broken line is one standard deviation from the mean).

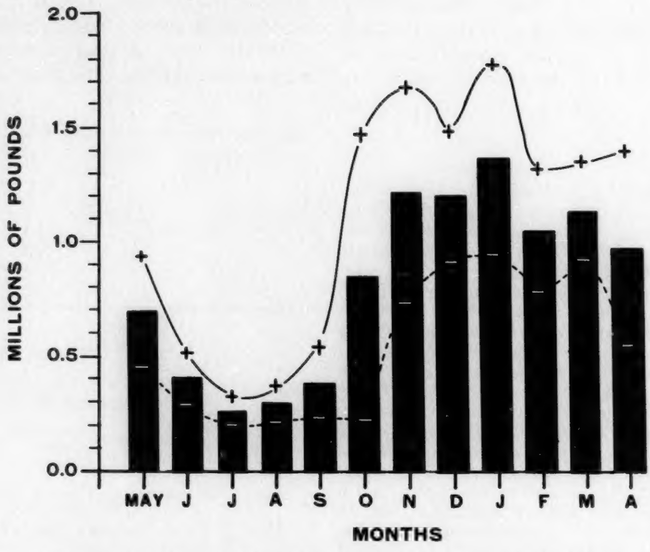

Figure 3.—Mean monthly pink shrimp landings from the Tortugas grounds (SS 1-3) from 1960 to 1979. Each + and − indicates one standard deviation from its mean.

Results

Landings

Annual landings by biological years, from 1960 to 1983, in statistical subareas 1 through 3 have averaged about 9.9 million pounds/year (Fig. 2). They have fluctuated from a high of slightly less than 13.4 million pounds in 1960 to a low of about 7 million pounds in 1982 and 1983. The small variation in annual landings, (S.D. = ±1.7 million pounds,

Table 1.—Monthly summary of total offshore pink shrimp catch in millions of pounds, total fishing effort in thousands of days, and CPUE for statistical subareas 1, 2, and 3 from 1981 through 1984 (an asterisk indicates period when trawling was permitted in toe of boot area).

Year and item	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Totals Jan.-Dec.	Totals May-Apr.
1984														
Catch	0.99*	0.80*	1.03*	1.18*	1.10*	0.12*	0.39*	0.23*	0.16	0.40	0.59	1.94	8.93	
Effort	1.6	2.3	1.9	1.18	1.16	0.3	0.7	0.5	0.5	0.8	0.9	1.7	15.4	
CPUE	608	341	531	646	684	465	532	451	329	498	678	1,100	580	
1983														
Catch	0.79	0.76	1.19	1.17*	0.85*	0.48*	0.26*	0.18*	0.13*	0.31*	0.29*	0.44*	6.84	6.94
Effort	2.0	1.8	1.9	2.0	1.4	1.1	0.6	0.4	0.3	0.7	0.6	1.0	13.7	13.7
CPUE	397	425	638	575	618	431	424	412	444	461	510	461	500	505
1982														
Catch	1.28	0.79	0.81	0.48	0.57	0.34	0.27	0.32	0.32	0.27	0.47	0.57	6.50	7.04
Effort	1.3	1.3	1.5	1.2	0.7	0.7	0.4	0.7	0.8	1.1	1.2	1.5	12.4	14.7
CPUE	1,003	601	52	404	797	488	611	493	384	258	387	391	526	479
1981														
Catch	1.55	0.74	2.50	2.78	1.58	0.83	0.50	0.44	0.71	0.78	1.02	0.99	14.43	10.22
Effort	2.4	1.5	1.9	2.2	1.3	1.2	0.6	0.6	1.0	0.5	1.6	0.6	15.5	12.8
CPUE	640	483	1,342	1,270	1,235	698	793	695	717	1,422	634	1,524	928	797

17.2 percent coefficient of variation) indicates a relatively stable fishery throughout this 24-year period. During 1960, 1965, 1971, 1972, 1977, 1980, 1982, and 1983, landings fell outside 1 S.D.

The 1981 shrimp catch of 10.2 million pounds was slightly larger than the historical average of 9.9 million pounds for 1960-79 and significantly larger than the 1982 and 1983 catch of 7.0 and 6.9 million pounds, respectively (Table 1).

The average monthly landings for 1960-79 showed an annual cycle with an amplitude that ranged from a high of 1.3 million pounds in January to a low of less than 0.3 million pounds in July (Fig. 3). Landings decrease from May through July, rise slightly in August, increase steadily through December, peak in January, decrease slightly in February, and remain constant through April.

The monthly pattern of shrimp landings in 1981, 1982, and 1983 biological years was substantially different from the historical pattern (Fig. 4, 5; Table 1). Compared with the monthly historical means, the landings in 1981 were significantly greater for May through July, and continued to be above the historical averages in August and September. Landings for October were average. Landings for the remaining months of the 1981 biological year, however, were below normal, particularly during February, March, and April.

Below average landings carried into the 1982 biological year for May and

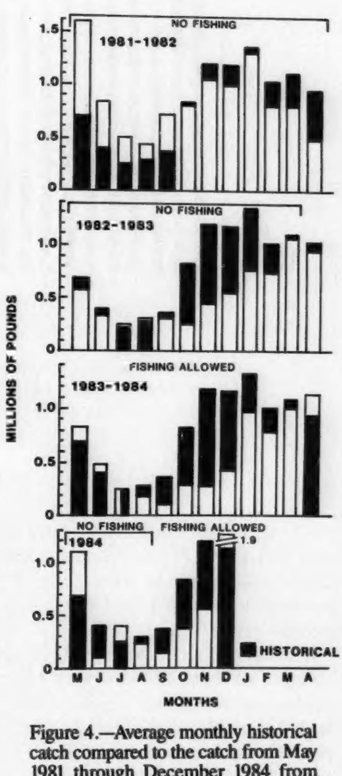

Figure 4.—Average monthly historical catch compared to the catch from May 1981 through December 1984 from the Tortugas grounds (SS 1-3).

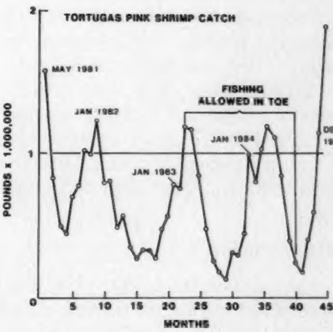

Figure 5.—Monthly landings in pounds from May 1981 through December 1984.

June. Landings for July 1982 were average, and for August they were slightly above normal. The large fall harvest, typical of the historical data, was definitely missing in 1982, with the difference in November being substantial and that in December being statistically lower.

Not until March-June 1983 did the monthly landings exceed the historical average. Below average landings from July through December continued through March 1984. The fall recruitment from September to November 1983 did not occur as in past years. Landings were above average in April and May, with extremely small shrimp being landed (Table 1, 2).

Table 2.—Index of recruitment on Tortugas fishery grounds using weight average, size count, and commercial landings. A + symbol indicates better than average recruitment, a blank indicates less than average recruitment.

	Biological year																								
Mo.	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984
May	+										+								+			+		+	+
Aug.	+	+			+	+	+													+			+		
Sept.	+	+			+	+	+		+					+		+				+	+				
Oct.	+	+				+	+																		
Nov.		+				+	+																		
Mar.	+		+							+								+			+		+		N.d.[1]
Apr.			+							+							+	+			+		+	+	N.d.

[1]N.d. = No data.

From May through November 1984, landings were well below the average historical landings. But, landings peaked in December 1984 with a catch of 1.9 million pounds, significantly above the historical landings for December. We noted differences in both 1981, 1982, and 1983 monthly landings compared with the historical monthly landings from 1960 to 1979, as well as the differences in the monthly landings between 1981, 1982, and 1983 (Fig. 4, 5; Table 1).

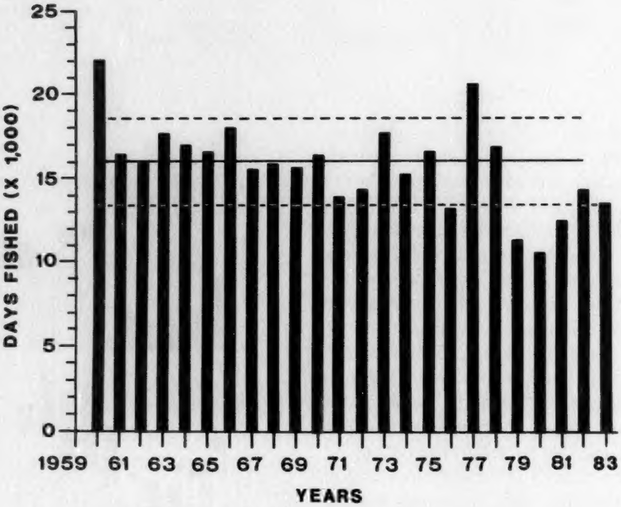

Figure 6.—Pink shrimp fishing effort on the Tortugas grounds (SS 1-3) by biological years for 1960-83. Solid line is the mean fishing effort, broken lines are at ± one standard deviation.

Fishing Effort

Fishing effort from 1960 to 1982 averaged about 16,000 days per year with a standard deviation of ±2,500 days and a 15.6 percent coefficient of variation. Highest fishing effort was 22,000 days expended in 1960 (Fig. 6). The lowest effort was 10,900 days expended in 1980. Fishing effort did not fluctuate greatly throughout the 24-year time period.

Fishing effort during the closed period was lower than the historical average by 12,800, 14,700 and 13,700 days in 1981, 1982, and 1983, respectively.

Relative Abundance

The relative abundance of pink shrimp, as expressed by catch per unit of effort (CPUE), is reported as pounds caught per 24-hour fishing day (pounds/day). For the Tortugas fishing grounds the annual CPUE (the mean of 12 monthly CPUE's) has been a remarkably stable parameter from 1960 through 1982 (Fig. 7). CPUE averaged 600 pounds/day with a standard deviation of ±79 pounds and a 13 percent coefficient of variation. The highest annual CPUE was 797 pounds/day recorded for 1981, and the lowest was 479 pounds/day recorded for 1982 and 505 pounds/day in 1983.

The uniformity of the annual average CPUE's for these 24 years is somewhat misleading as there are large differences in the monthly CPUE's between months (Fig. 8). Measures of monthly CPUE from 1960 to 1979 reveal low CPUE's of around 500 pounds/day in May and June. They increase to 650 pounds/day in July and August, and increase to 800 pounds/day in September. A peak is reached at about 940 pounds/day in October, after which there is a steady decline to a low of about 450 pounds/day in February. In March and April, CPUE's increase slightly to about 500 pounds/day.

With the closure of the sanctuary area to trawling in May 1981, the monthly CPUE dropped from the May figure of >1,200 pounds/day to around 700 pounds/day in June and remained at that level through September. A spike occurred in October at 1,400 pounds/day,

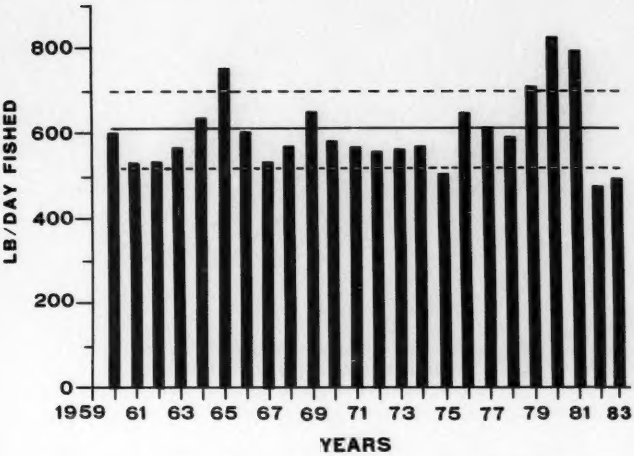

Figure 7.—Catch per unit effort by biological years for 1960-83 in statistical subareas 1, 2, and 3. Solid line is the mean, broken lines are ± one standard deviation away.

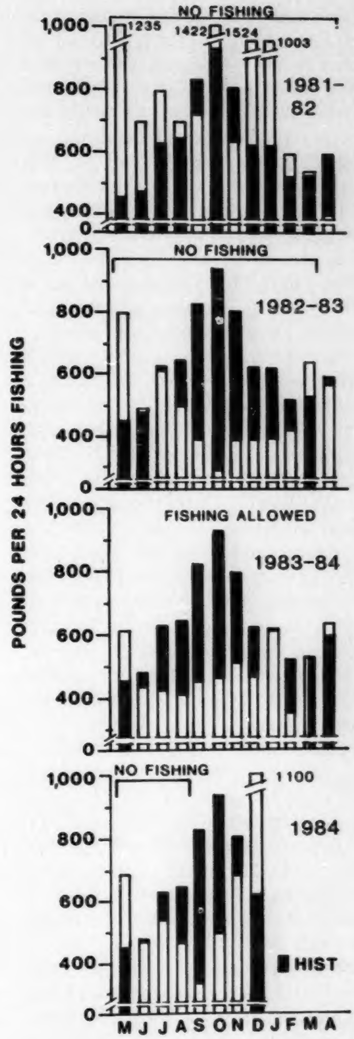

Figure 9.—Average monthly historical CPUE compared with the CPUE from may 1981 through December 1984.

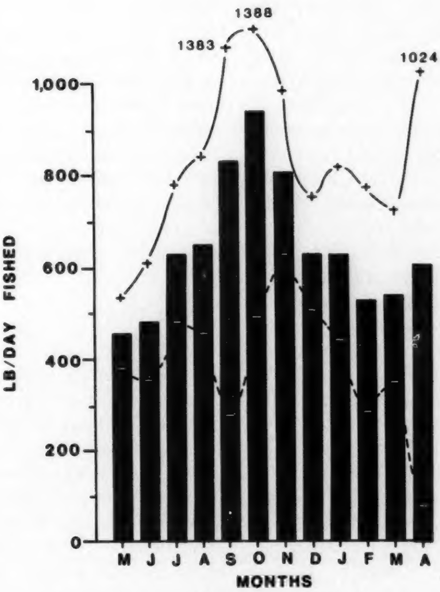

Figure 8.—Monthly CPUE means for shrimping on the Tortugas grounds (SS 1-3) for the biological years 1960-79. Each + is one standard deviation from its mean.

but in November the CPUE dropped to about 600 pounds/day, rose in December to about 1,500 pounds/day, followed by a gradual decline to about 400 pounds/day by April (Fig. 9). The CPUE during the 1981 biological year fluctuated radically, whereas in the 1982 biological year the CPUE was much steadier, averaging about 478 pounds (Fig. 9 and Table 1), and from September 1982 through February 1983 CPUE was ≤400 pounds per day.

With the opening of the toe area of the boot to fishing in March 1983, CPUE rose to 638 pounds/day and stayed at that level through May. From June through December 1983 the CPUE was extremely low, and well below the historical monthly average (Fig. 8). With the exception of April and May 1984 the CPUE was well below the monthly historical average through November 1984. The toe of the boot area was again closed to fishing in August 1984 and in December the CPUE was almost double the December historical average.

In comparing the monthly CPUE's with the historical data, we plotted a ratio of the monthly CPUE from January 1981 through December 1984 over the historical CPUE for 1960-79. These data revealed a higher relative abundance of shrimp on the grounds in 1981 than the historical norm. In 1982 the shrimp abundance was below the historical norm except in May (Fig. 10). With the opening of the toe to fishing in April 1983, the abundance on the Tortugas grounds was less than during the 1960-79 period except for April and May 1984. After the close of fishing in the toe in August 1984, abundance remained low until December 1984.

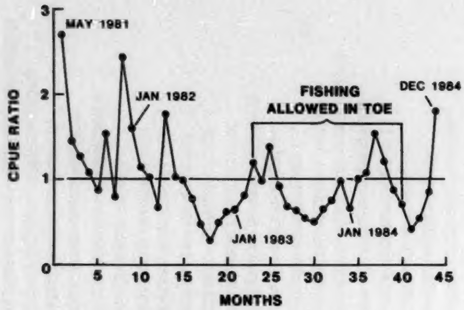

Figure 10.—Ratios of current monthly CPUE's to their corresponding historical means for the Tortugas pink shrimp fishery (SS 1-3).

Size

Recruitment into the Tortugas shrimping grounds occurs during two periods of the year. The first recruitment occurs usually from August through October, with a second recruitment from March through May. The average size of shrimp measured by size categories of the FIMD has been used as an indicator of recruitment on the Tortugas grounds (Klima et al., In press). These data show large fluctuations within the 1960-79 period.

However, to provide a better measure of recruitment, we have examined the pounds of shrimp landed during these critical months (Table 2). If the landings for a given month exceeded the historical average for the data set 1960-79, and if the average weighted mean size for that month was greater than the historical average, we called recruitment "good" or "better than average" for that month. The pluses on Table 2 indicate periods when recruitment was strong according to these criteria. Good recruitment in two consecutive months occurred in 1960, 1961, 1962, 1964, 1965, 1966, 1969, 1977, 1979, 1980, and 1982.

In March and April 1981, before the closure, there was a major recruitment of small shrimp onto the Tortugas grounds. Apparently there was no major movement of small shrimp onto the fishery grounds during the remainder of 1981. Not until March, April, and May of 1983 was there major recruitment again onto the Tortugas fishing grounds.

No detectable major recruitment was observed during the fall of 1983. Good recruitment was observed in April and May 1984. The commercial landings did not show large concentration of small shrimp entering the fishery from August to November 1984. This may be due to prohibition of fishing in the sanctuary and especially in the toe area from August to December 1984. Fishing increased dramatically in December 1984, with the large catches of 21-30 count shrimp composing over 50 percent of the landings. The ratio of mean monthly sizes from May 1981-December 1984 to the historical mean sizes showed some increase through December 1982 in size as would be expected if the management measures were effective (Fig. 11, Table 3). However, with the opening of the tow area to fishing in April 1983, the average monthly size of shrimp landed was consistently smaller than the historical monthly sizes (Fig. 11, Table 3). When the toe area was again closed to fishing in August 1984 the size of shrimp increased dramatically.

Klima et al. (In press) have shown, using G-tests, significant differences in the monthly composition of size categories between 1981 and 1982 and between 1981 as well as 1982 and the monthly historical size compositions. Although we have not gone through the rigors of statistical testing of the data from April 1983 to August 1984, we feel the size composition is clearly different from that of the closed fishing time from May 1981 to February 1983 (Fig. 10, Table 3).

Fishing Effort and Catch

We examined the landings in millions of pounds versus total projected fishery effort for 1960 through 1982 (Fig. 12). These data indicate the condition of the fishery, and a few years stand out: 1960, 1965, 1977, and 1980. These data points show high landings at various levels of fishing effort. The 1981 landings were high with relatively low fishing effort, whereas 1982 and 1983 landings were low with moderate levels of fishing effort.

Discussion

The permanent closure of the Tortugas Sanctuary was established in May 1981, but a small and extremely important part of the extremely southern end

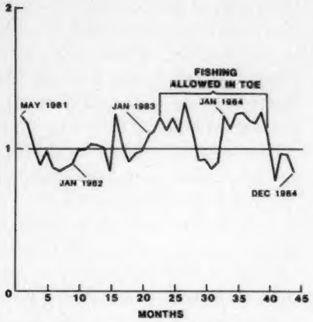

Figure 11.—Ratios of monthly mean number of pink shrimp per pound from May 1981-December 1984 to monthly mean number of pink shrimp per pound for 1960-79.

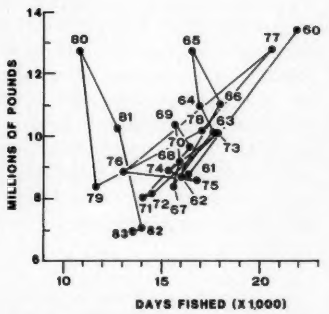

Figure 12.—Catch versus fishing effort for biological years 1960-82 from the Tortugas grounds (SS 1-3).

Table 3.—Monthly average weighted number of pink shrimp per pound for 1960-79, 1981, 1982, 1983, and 1984 (+ indicates larger size group and – indicates smaller size group than historical average; bracketed portion indicates open fishing in toe of the boot).

Month	1960-79 Average number/lb.	1960-79 Standard deviation	1981 Average number/lb.	1982 Average number/lb.	1983 Average number/lb.	1984 Average number/lb.
May	46.8	5.1	57.4+	48.4+	[56.8+	[55.9+
June	45.2	4.5	52.7+	45.7+	50.2+	53.1+
July	44.0	4.7	44.2+	36.6–	58.0+	55.0+
August	44.0	7.7	38.9–	55.0+	49.6+	46.9+]
September	48.7	7.9	47.5–	49.0+	44.2–	36.9–
October	47.9	4.8	41.4–	43.3–	44.0–	45.8–
November	43.1	3.3	36.4–	41.3–	36.6–	41.0–
December	40.2	2.8	34.9–	39.3–	36.1–	35.2–
January	40.2	3.1	35.6–	43.6+	49.4+	
February	42.7	3.1	42.1–	48.0+	48.1+	
March	47.5	4.4	46.8–	57.5+	58.7+	
April	48.3	5.8	49.8+	[54.1+]	60.5+]	

of the sanctuary was open to fishing from April 1983 through August 1984. In evaluating the management regulations, we have specifically looked at landings, effort, CPUE, and size composition from May 1981 through December 1984 and have compared these catch statistics with the historical data from 1960 through 1979, using the biological year of May through the following April.

The Tortugas fishery has been very stable, with average annual production of about 9.9 million pounds; it does not fluctuate greatly from year to year. The fishery is bounded naturally by trawable bottoms of loggerhead sponges and coral reefs where pink shrimp are protected from trawling even though they may be present in high concentrations. The large area of untrawlable bottom surrounding the fishery grounds may be the reason why this fishery has been so stable since 1960.

Historically, the recruitment of small shrimp onto the Tortugas grounds occurs between September and November, and in certain years there is also a major spring recruitment. In March and April 1981 (prior to the closure of the sanctuary), there was good recruitment of small shrimp onto the Tortugas grounds. That recruitment continued through May 1981, the closure period, and sustained the fishery through the remainder of 1981. The 1981 catch amounted to 10.2 million pounds. However, there was no strong recruitment onto the Tortugas grounds again until March, April, and May of 1983. Consequently, the fishery from May 1982 through April 1983 produced an all-time low of about 7 million pounds of shrimp. It would appear that the fishery had collapsed, but the drop was due primarily to limited recruitment of small juveniles onto the grounds.

In April of 1983 the toe of the boot area of the sanctuary was open to fishing and the fleet took advantage of this opening and concentrated their effort on the extremely small and abundant shrimp, which was reflected in an increase of the average size of shrimp landed as well as landings of over 1.0 million pounds per month. Recruitment was poor in the fall of 1983. Above average recruitment was again observed in both April and May 1984. This peak spring 1984 recruitment was again rapidly harvested since the toe area was open to fishing, with a catch of over 1.0 million pounds per month of extremely small shrimp (Fig. 5, 11). After the closure of the toe area to fishing in August 1984, the average size increased to a much larger size than the respective monthly historical size.

The fishery from May 1982 through April 1984 produced an all-time low of about 7 and 6.9 million pounds for the biological years 1982 and 1983, respectively. Production from May to December 1984 was relatively low with a total yield of only 3.0 million pounds. The only exceptional month was December 1984, in which 1.94 million pounds of large shrimp (33/pound average) were landed.

We believe that the high production of large shrimp during December was due to the spring recruitment of shrimp that did not move onto the fishing grounds in August and September, but stayed either in the loggerhead sponge area north of the fishery or in the sanctuary. This stock apparently moved onto the grounds in November-December 1984. They were basically protected from the fishery either by the sanctuary or by the loggerhead sponges. However, this remains purely conjecture. For example, 150-200 count shrimp would take about 6 months to reach a size of 20 count; therefore, shrimp of this size recruited to the sanctuary area from the Everglades during May, would take

about 6 months before they reach a size of 20 count shrimp (Berry, 1967). Further, the December 1984 fishery was basically concentrated in the extreme northern and northeastern part of the Tortugas fishery.

The tone of the fishery from 1981 to 1984 was set by the amount of recruitment and the opening and closing of fishing in the toe area. With good recruitment in the March through April 1981 period, the stage was set for a good fishery, whereas the lack of recruitment in 1982 and 1983 resulted in devastatingly low production. Good recruitment in the spring of 1983 coincided with the opening of the toe area to fishing, which we believe reduced the total yield because of the excessive harvest of small shrimp.

Summary

Commercial pink shrimp landings from the Tortugas fishery were relatively stable from 1960 to 1979 and deviated very little from the mean of 9.9 million pounds with a standard deviation of about 1.7 million pounds and a 17 percent coefficient variation. This indicates a very stable fishery throughout this period.

The Tortugas Sanctuary was closed to all trawling from May 1981 through 15 April 1983. Commercial landing statistics from May 1981 through March 1983, during the two closure years, were dramatically different. Production in 1981 amounted to 10.2 million pounds, but it dropped to about 7 million pounds in 1982.

In April 1983 the toe of the boot was open to fishing through August 1984. Landings during the 1983 biological year were 6.9 million pounds, again well below the annual historical average of 9.9 million pounds. Annual production from April 1983 to March 1984 amounted to 7.1 million pounds. Annual production from January to December 1984 amounted to 8.1 million pounds. Monthly landings of over 1 million pounds were recorded in March, April, and May, a period of open fishing in the toe. After closing the toe area to fishing in August 1984, monthly landings remained lower than their historical average until December when they peaked at 1.9 million pounds, well above the December historical average.

Annual fishing effort from 1960 to 1979 averaged about 16,000 days/year and did not fluctuate greatly. Fishing effort during the closed period was 12,800, 14,700, and 13,700 days in 1981, 1982, and 1983, respectively, less than the historical average.

The relative abundance of shrimp on the Tortugas grounds as measured by the annual CPUE was remarkably stable from 1960 through 1982, with an average of 619 pounds per day and a standard deviation of ± 79 pounds. The highest historical CPUE was 829 pounds/day recorded in 1980, the lowest figures were 479 pounds/day recorded in 1982 and 505 pounds/day in 1983. Both figures were significantly different than the historical CPUE during the period 1960-79.

The size distributions of shrimp landed in 1981, 1982, and 1983 were different from each other, and were also different than the period between 1960 and 1964 and the period between 1975 and 1979.

The yield in the Tortugas fishery is based on recruitment and amount of fishing effort expended on small shrimp in the sanctuary and/or toe of the boot area.

Excellent recruitment was observed in March, April, and May 1981, with little observed recruitment in the fall of 1981, and little recruitment in the spring and fall of 1982. In the spring of 1983, good recruitment was noted in March, April and May, with below average recruitment in the fall of 1983. Again, excellent recruitment was noted in April and May 1984, with little observed recruitment in the fall of 1984.

Landings as well as relative abundance as measured by CPUE were low throughout 1982 as well as in January and February 1983 and from April 1983 to November 1984. The only exception to low landings and low levels of abundance was the high CPUE in May 1983 and April and May 1984 associated with the harvesting of small shrimp as they moved into the toe area of the boot and onto the fishing grounds.

Fishing within the toe area of the boot from April 1983 to August 1984 allowed the fishery to exploit small shrimp, resulting in an increase in the average size groups harvested and reducing overall yield to the fishery. Large, predominantly 21-30 count, shrimp were caught in great abundance in December 1984, presumably a result of protecting emigrating juvenile shrimp.

Literature Cited

Berry, R. J. 1967. Dynamics of the Tortugas (Florida) pink shrimp population. Ph.D. Thesis, Univ. R.I., Narragansett.

__________. 1970. Shrimp mortality rates derived from fishery statistics, p. 66-78. *In* Proc. Gulf Carib. Fish. Inst., 22nd Annu. Sess.

GMFMC. 1980. Proposed rules. Fishery management plan for the shrimp fishery for the Gulf of Mexico. Fed. Regist. 45(218):7410-74309.

Klima, E. F. 1980. Catch statistics - data needs of the southwestern South American shrimp populations. WECAF Rep. 28:123-130.

__________, G. A. Matthews, F. J. Patella. In press. A synopsis of the Tortugas Pink Shrimp Fishery, 1960-1983, and the impact of the Tortugas sanctuary. N. Am. J. Fish. Manage.

Lindner, M. J. 1965. What we know about shrimp size and the Tortugas fishery. Proc. Gulf Carib. Fish. Inst., 18:18-25.

Fisheries Resource Assessment of the Mariana Archipelago, 1982-85

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Introduction

The Resource Assessment Investigation of the Mariana Archipelago (RAIOMA) was a 5-year program initiated by the Honolulu Laboratory of the National Marine Fisheries Service's Southwest Fisheries Center in 1980 to quantify the distribution and sustainable yield of insular fishery resources with commercial potential in the Mariana Archipelago (Fig. 1).

To identify fishery resources with commercial value or potential, data from the commercial landings collected by the Governments of Guam and the Commonwealth of the Northern Marianas together with data from earlier research cruises were used to rank species of fish by their economic potential and importance to the subsistence fishery. Four species groups were thus identified as important fishery resources in the Marianas: 1) Tunas, 2) deepwater snappers and groupers, 3) deepwater shrimp *Heterocarpus* spp., and 4) akule or bigeye scad, *Selar crumenophthalmus* (Polovina[1]).

The tuna resource has the greatest economic potential, but an assessment of the tunas in the Marianas would require an assessment of the tuna stocks in the western Pacific which was beyond the scope of the program. Thus, information on the tuna resource in the Marianas was obtained from historical catch and effort statistics provided by Japanese longliners and baitboats operating in

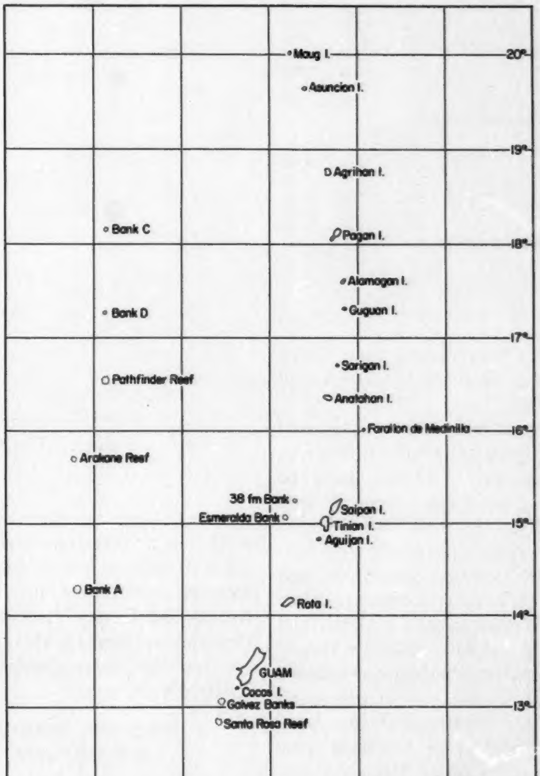

Figure 1.—The Mariana Archipelago with the 22 islands and banks sampled during the RAIOMA Program.

[1]Polovina, J. J. 1981. Planning document for the assessment of marine resources around Guam and the Commonwealth of the Northern Mariana Islands. Honolulu Lab., Southwest Fish. Cent., Natl. Mar. Fish. Serv., NOAA, Honolulu, HI 96812. Admin. Rep. H-81-10, 13 p.

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Table 1.—Bottom fish catch per unit effort (CPUE) and standard error (SE), by island and bank for the six cruises.

Area	No. of drifts	Mean drift CPUE (numbers)	SE	Latitude N
Northern Islands and Banks				
Maug	7	5.03	1.02	20°02′
Asuncion	17	2.16	0.49	19°40′
Agrihan	45	4.20	0.31	18°46′
Pagan	100	4.57	0.40	18°06′
Alamagan	118	2.37	0.19	17°36′
Guguan	32	3.01	0.30	17°19′
Sarigan	28	2.82	0.37	16°43′
Anatahan	38	2.31	0.23	16°21′
38-Fathom	61	3.12	0.26	16°20′
Esmeralda	114	2.29	0.15	14°58′
Average drift CPUE		3.19		
Southern Islands and Banks				
Farallon de Medinilla	32	3.29	0.65	16°01′
Saipan	17	1.72	0.34	15°10′
Tinian	20	1.96	0.29	15°00′
Aguijan	13	3.84	0.98	14°52′
Rota	19	1.91	0.40	14°10′
Guam	20	1.53	0.35	13°25′
Galvez and Santa Rosa	41	2.95	0.31	13°00′
Average drift CPUE		2.46		
Seamounts				
Bank C	8	5.91	1.57	18°08′
Bank D	20	5.85	0.51	17°09′
Pathfinder	136	4.58	0.23	16°30′
Arakane	84	3.36	0.24	15°38′
Bank A	24	3.71	0.57	14°12′
Average drift CPUE		4.68		

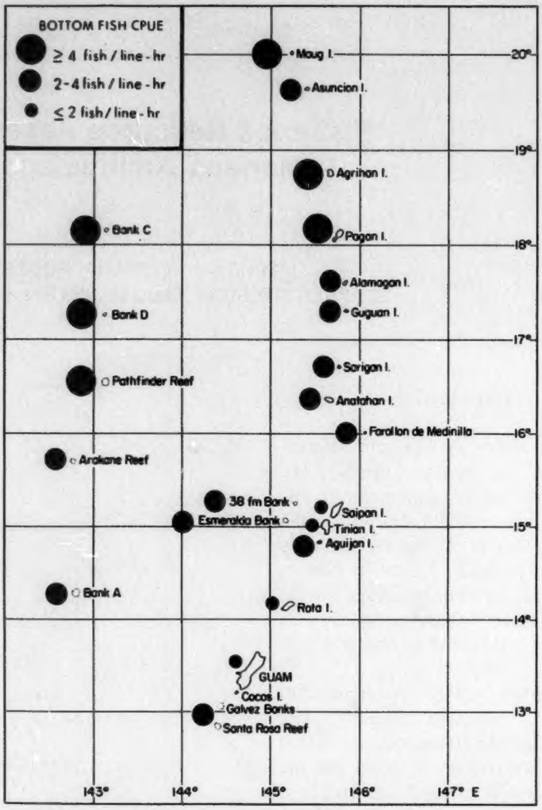

Figure 2.—The bottom fish CPUE grouped into three catch levels.

the fishery conservation zone (FCZ) around the Marianas (Polovina and Shippen[2]).

The insular resources were assessed by a field program which consisted of six cruises, each of 40 days, using the NOAA ship *Townsend Cromwell*, from May 1982 through June 1984. On these cruises a systematic survey was conducted to measure geographic and seasonal variation of deepwater bottom fishes and shrimps at 22 islands and banks (Fig. 1). Also, intensive fishing experiments were conducted to estimate catchability of the bottom fishes and shrimps. A collection of all specimens which appeared to represent new records was developed. Two aerial surveys were made in an attempt to estimate the abundance of akule in the Marianas. Finally bathymetric surveys were conducted and chartlets produced for 11 islands and banks where existing bathymetric data were insufficient for fishing and fishery assessment work (Polovina and Roush[3]). This report summarizes the main findings of the RAIOMA Program.

Deepwater Snappers and Groupers

At each island and bank, an attempt was made to conduct a systematic fishing survey of the bottom fish community in the 125-275 m depth range. A total of 7,621 bottom fishes of over 30 species were caught with handline gear during the six cruises. Gindai, *Pristipomoides zonatus*, accounted for 51.2 percent of the catch, and three species (gindai, yellowtail kalekale, *P. auricilla*; and ehu, *Etelis carbunculus*) accounted for 79.1 percent of the total catch (Polovina, In press).

Catch per unit effort (CPUE) was measured by the number of fish caught per line-hour. For each bank, bank CPUE was computed as the mean of all the drift CPUE values, where a drift CPUE is the number of fish caught during an uninterrupted drift of the vessel while it is fishing in the 125-275 m depth range divided by the drift line-hours. The mean drift CPUE is presented for all 22 banks and islands in Table 1 and Figure 2.

[2]Polovina, J. J., and N. T. Shippen. 1983. Estimates of the catch and effort by Japanese longliners and baitboats in the fishery conservation zone around the Mariana Archipelago. Honolulu Lab., Southwest Fish. Cent., Natl. Mar. Fish. Serv., NOAA, Honolulu, HI 96812. Admin. Rep. H-83-1, 42 p.

[3]Polovina, J. J., and R. C. Roush. 1982. Chartlets of selected fishing banks and pinnacles in the Mariana Archipelago. Honolulu Lab., Southwest Fish. Cent., Natl. Mar. Fish. Serv., NOAA, Honolulu, HI 96812. Admin. Rep. H-82-19, 15 p.

Taken by bank type, the seamounts have the greatest mean drift CPUE (4.68 fish/line-hour), followed by the northern islands (3.19 fish/line-hour), and then the southern islands (2.46 fish/line-hour). The main inhabited islands of the Marianas are Guam, Saipan, Rota, and Tinian—all in the southern group. Fishermen at these islands exploit the local stocks of bottom fishes which most likely account for the relatively low CPUE values for the islands. The mean of the bank CPUE for the uninhabited islands and banks in the southern group is 3.36 fish/line-hour which suggests that when islands with heavy fishing mortality are excluded, there is no difference in bottom fish standing stock between the northern and unfished southern islands. The seamounts, however, appear to support a higher standing stock than the northern or southern islands and banks.

Bottom fish species were stratified by depth. The results, summarized in Table 2, show that the centers of distribution for black ulua or black jack, *Caranx lugubris*; lehi, *Apharens rutilans*; and the yelloweye opakapaka, *P. flavipinnis*; and pink opakapaka, *P. filamentosus*, were between 164 and 183 m (90 and 100 fathoms). Similarly, yellowtail kalekale, kahala or greater amberjack, *Seriola dumerili*; and gindai were most abundant between 183 and 201 m (100 and 110 fathoms). Species with deeper depth distributions, i.e., mean depth of capture >201 m (110 fathoms), were the pink kalekale, *P. sieboldii*; black grouper, *Epinephelus* sp.; ehu, and onaga, *Etelis coruscans*. Studying each fishing bank individually showed that, overall, depth distributions were similar over the archipelago.

The approach to yield estimation for the deepwater bottom fishes is described in detail by Polovina and Ralston (In press). Using an estimate of catchability obtained from an intensive fishing experiment and a measure of bottom fish habitat together with the estimated relative abundance from the systematic survey, the total bottom fish biomass which can be exploited with handline gear was computed. The Beverton and Holt (1956) yield equation, together with estimates of growth and mortality parameters obtained from otolith and size-frequency data, was used to first determine the age of entry for each of the major species which will maximize the yield per recruit. Then with the estimate of unexploited biomass the equilibrium yield was estimated as a function of fishing mortality. Also the change in the spawning stock biomass relative to its level in the absence of exploitation can be computed with the Beverton and Holt yield equation as a function of fishing mortality.

The equilibrium yield for the multispecies bottom fish complex fished with handline gear in the 125-275 m depth range for the 22 islands and banks of the Mariana Archipelago increases rapidly as a function of fishing mortality to a level of about 100 metric tons (t) and beyond that exhibits a gradual increase with increasing fishing mortality (Table 3). In view of the flat-topped, yield curve which assumes constant recruitment and does not incorporate any economic considerations, an approach to determining the optimum equilibrium yield has been suggested (and adopted for several North Atlantic fisheries) as the yield corresponding to that level of effort where an increase of one unit of effort will increase the catch by 0.1 of the amount caught by the very first unit of effort (Gulland, 1983; 1984).

The value of $F_{0.1}$ for the bottom fish resource in the Marianas is estimated to be $F = 1.0$, and the corresponding annual equilibrium yield is 109 t (Table 3). An approximate 95 percent confidence interval (CI) for this yield is 81-137 t (Polovina and Ralston, In press). About 70 percent of this yield would come from the southern islands and banks, 27 percent would come from the northern chain, and only 3 percent from the seamounts (Table 4; Fig. 3). At a fishing mortality of 1.0, the spawning stock biomasses for the seven major species are reduced 20-42 percent of their unexploited levels. Although the spawner recruit curve for these species is unknown, as a generic lower bound, the spawning stock biomass should not be

Table 2.—Mean depth of capture for the principal bottomfish species captured during the RAIOMA cruises (N = sample size).

	Mean depth		
Scientific name	Meters	Fathoms	N
Caranx lugubris	166	91	270
Pristipomoides flavipinnis	170	93	499
P. filamentosus	170	93	191
Aphareus rutilans	174	95	81
P. auricilla	188	102	1,166
Seriola dumerili	196	107	47
P. zonatus	199	109	3,890
Epinephelus sp.	214	117	38
P. sieboldii	214	117	57
Etelis coruscans	218	119	200
E. carbunculus	225	123	950

Table 3.—Annual equilibrium bottom fish yield in metric tons (t) for the age at entry which maximizes the yield per recruit for each species.

Fishing mortality (F)	Total yield (t)
0.1	35
0.5	91
[1]1.0	109
1.5	114
2.0	116
2.5	116

[1]$F_{0.1}$ and $Y_{0.1}$ as defined by Gulland (1983).

Table 4.—Annual equilibrium bottom fish yield and yield per nautical mile of 200 m contour for the age at entry which maximizes the yield per recruit at a level of fishing mortality of F = 1.0.

Area	Total yield (t/year)		Yield[1]/n.mi. of 200 m contour
Northern Islands and Banks			
Maug	2.7		262.2
Asuncion	2.1		188.4
Agrihan	5.6		303.6
Pagan	7.7		255.1
Alamagan	2.0		177.6
Guguan	1.7		179.0
Sarigan	1.6		193.8
Anatahan	2.5		144.2
38-Fathom	0.5		187.3
Esmeralda	2.9		237.4
Subtotal	29.3	Mean	212.9
Southern Islands and Banks			
Farallon de Medinilla	16.7		216.6
Saipan	13.4		254.1
Tinian	8.8		303.9
Aguijan	4.2		266.7
Rota	6.1		192.2
Guam	17.2		201.6
Galvez and Santa Rosa	8.6		164.2
Subtotal	76.0	Mean	228.5
Seamounts			
Bank C	0.9		288.2
Bank D	1.1		351.2
Pathfinder	0.9		303.5
Arakane	0.6		199.6
Bank A	0.6		179.7
Subtotal	4.1	Mean	264.4

Total yield from all banks = 109 t per year.

[1]Yield in kg/year.

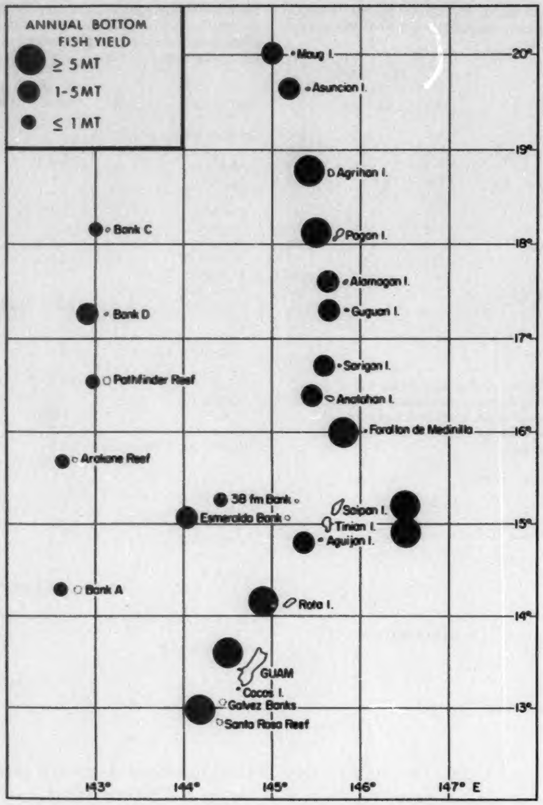

Figure 3.—Annual bottom fish yield grouped into three yield levels.

Table 5.—The percentage of annual sustainable yield by species group for fishing mortality of 1.0/year at age of entry which maximizes yield per recruit.

Species	Annual sustainable yield (percent)
Caranx lugubris	8.3
Pristipomoides filamentosus	8.2
P. auricilla	7.3
P. flavipinnis	28.7
P. zonatus	23.1
Etelis coruscans	5.0
E. carbunculus	5.9
Others	13.5

Table 6.—Estimates of Guam fish landings, 1980-84[1].

	Landings (t)	
Year	Pelagic species	Deep bottom fish
1980	198	6
1981	223	12
1982	240	9
1983	189	11
1984[2]	265	20

[1]Based on data from the Honolulu Laboratory's Western Pacific Fishery Information Network file on the Guam Division of Aquatic and Wildlife Resources offshore creel survey. Confidence interval ±30 percent of catch for pelagics and ±50 percent of catch for bottom fish.
[2]Estimate expanded from data from period June-September 1984.

reduced below 20 percent of its unexploited level if a serious reduction of recruitment is to be avoided (Beddington and Cooke, 1983).

The means of the annual equilibrium yield per nautical mile of 200 m contour for the northern banks, southern banks, and western seamounts are 212.9, 228.5, and 264.4 kg/n.mi., respectively. The ratio of total yield for the archipelago to the total length of the 200 m contour is 222.4 kg/n.mi. (95 percent CI of 165.3-279.6 kg/n.mi.) (Table 4). These values suggest that the stocks in the Marianas are slightly less productive than those in Hawaii where a lower-bound estimate of maximum sustainable yield of 272 kg/n.mi. of 200-m contour was obtained from a stock production model applied to commercial catch and effort data (not including the recreational fishing component) of snappers and groupers from Penguin Bank (Ralston and Polovina, 1982).

If the entire archipelago is fished, *P. flavipinnis* and *P. zonatus* together will comprise about 50 percent of the catch (Table 5).

Over the period 1980-84 it is estimated that annual bottom fish landings have increased from 6 t in 1980 to 20 t in 1984 (Table 6). Although the location data were not always obtained for these data, it appears that 65-95 percent of this catch comes from around Guam and the remainder comes from Galvez Banks and Santa Rosa Reef south of Guam or areas in the Commonwealth of the Northern Marianas. Given the estimated equilibrium yield of 17.2 t for Guam and that the CPUE around Guam is about half of the archipelago average, it appears that Guam is already fished at its maximum sustainable yield and most probably overfished on the leeward coast. There may be an opportunity to increase the yield with more fishing effort directed toward Galvez Banks and Santa Rosa Reef, but most of the additional yield potential lies in the islands and banks to the north of Guam (Table 4).

The commercial landings at Saipan have ranged from 4 to 10 t, compared with the estimate of equilibrium yield of 29 t from Saipan, Tinian, Aguijan, and Esmeralda Bank (Tables 4 and 7). These sites are all within 30 miles of Saipan suggesting that there is an opportunity to increase bottom fish landings from Saipan, Tinian, Aguijan, and Esmeralda Bank with a bottom fishing fleet operating out of Saipan and Tinian.

Based on the catchability estimated from the intensive fishing experiment,

Table 7.—Estimates of the Commonwealth of the Northern Mariana Islands commercial landings, 1981-83[1].

	Landings (t)	
Year	Pelagic species	Deep bottom fishes
1981	40.8	5.3
1982	47.2	3.7
1983	89.2	6.4
1984	123.8	9.9

[1]Data from the Honolulu Laboratory's Western Pacific Fishery Information Network.

Table 8.—Depth stratification for *Heterocarpus* spp.

Depth			Depth		
Meters	Fathoms	CPUE[1]	Meters	Fathoms	CPUE[1]
Heterocarpus ensifer			*H. laevigatus* (continued)		
320	175	0			
366	200	0.18	686	375	1.93
412	225	0.15	732	400	1.64
458	250	0.10	778	425	2.33
503	275	0.09	824	450	1.10
549	300	0.02	869	475	0.87
595	325	0.02	915	500	0.36
640	350	0.03	961	525	0.05
686	375	0	1,006	550	0.02
732	400	0	1,052	575	0.02
H. laevigatus			*H. longirostris*		
366	200	0	824	450	0
412	225	0.08	869	475	0.11
458	250	0.01	915	500	0.29
503	275	0.62	961	525	0.38
548	300	2.10	1,006	550	0.46
595	325	1.95	1,052	575	0.75
640	350	1.75	1,098	600	0.63

[1]CPUE in kg/trap.

the fishing mortality of 1.0 per year is equivalent to an annual fishing effort of 74,153 line-hours. Thus, for example, 15 small vessels each with two electric or hydraulic gurdies which fish 12 hours a day for 200 days a year can achieve this level of fishing effort and would have a fleet catch rate of 1.5 kg/line-hour with an annual average catch of 7.3 t per vessel.

Deepwater Shrimp

Deepwater shrimp, *Heterocarpus* spp., was sampled at depths from 360 to 900 m (about 200-500 fathoms). The sampling gear consisted of Quonset[4] shaped traps about 90 by 66 cm at the base and a height of 46 cm. The frame is made of rebar and is covered with a wire mesh which is then covered on the top and two sides with a canvas cover. The entrances to the trap are two cones on opposite sides of the trap. Five traps were used on a string with a separation of about 40 m between traps. The traps were baited with mackerel.

The shrimp catches were primarily *H. ensifer*, *H. laevigatus*, and *H. longirostrus* which are stratified by depth (Table 8). The catch rates of *H. laevigatus* were the highest of the three species and were greatest in the depth range 500-825 m.

The systematic survey of the relative abundance of *Heterocarpus* spp. in the 500-825 m depth range found little seasonal variation but considerable variation in CPUE between banks. As with the bottom fishes, the seamounts had the highest catch rates (2.37 kg/trap-night), followed by the northern islands and banks (2.01 kg/trap-night), and then the southern islands and banks (1.39 kg/trap-night) (Table 9; Fig. 4).

A growth equation for *H. laevigatus* was estimated from a time-series of length-frequency data and estimates that the shrimp become susceptible to trap fishing at age 2 and that the females become sexually mature at age 4.5 (Moffitt and Polovina[5]). Yield-per-recruit analysis indicates that an age-of-entry of 2 maximizes the yield per recruit. The Beverton and Holt yield equation estimates equilibrium yield as a function of fishing mortality and the ratio of spawning stock biomass under exploitation to the unexploited spawning stock biomass (Table 10). At a fishing mortality of $F = 0.5$, the spawning stock is reduced to 20 percent of its original level in the absence of exploitation which has been suggested as a generic lower bound before a substantial decrease in recruitment may occur (Beddington and Cooke, 1983). At $F = 0.5$ the equilibrium yield from the entire archipelago in the 500-825 m depth range is estimated at 162 t, with a 95 percent CI of 102-218 t, which would almost exclusively consist of *H. laevigatus*. About 85 percent of this yield would come from the southern islands and banks, 13 percent from the northern islands and banks, and about 2 percent from the seamounts (Table 11; Fig. 5).

Table 9.—Catch rates and habitat for *Heterocarpus* spp. in the 500-825 m depth range.

Area	CPUE (kg/trap)	Area (n.mi.²) (500-825 m)
Northern Islands and Banks		
Maug	1.88	3.83
Asuncion	2.11	5.93
Aguijan	1.96	12.39
Pagan	2.17	16.19
Alamagan	2.18	11.43
Guguan	2.52	5.60
Sarigan	1.45	4.55
Anatahan	2.36	10.89
38-Fathom	2.12	6.37
Esmeralda	1.35	2.03
Mean = 2.01		
Southern Islands and Banks		
Farallon de Medinilla	0.97	88.55
Saipan	2.06	213.99
Tinian	1.81	73.80
Aguijan	1.61	39.36
Rota	1.02	197.31
Guam	0.72	44.24
Galvez and Santa Rosa	1.78	50.77
Mean = 1.39		
Seamounts		
Bank C	2.07	2.71
Bank D	2.72	2.71
Pathfinder	2.79	2.71
Arakane	1.91	2.10
Bank A	1.43	3.33
Mean = 2.37		

Table 10.—Equilibrium yield (t) for *Heterocarpus laevigatus* in the 500-825 m depth range and relative spawning stock biomass as a function of fishing mortality (*F*).

F	Total yield (t) in 500-825 m depth	Spawning stock biomass under *F*/unexploited spawning biomass
0.1	56.3	0.70
0.2	95.6	0.51
0.3	124.2	0.37
0.4	145.1	0.27
0.5	161.5	0.20
0.6	174.1	0.15
0.7	181.1	0.11

Although there have been several short-lived attempts to harvest deepwater shrimp around Guam, there is currently no shrimp fishing around Guam or anywhere else in the Marianas. Given that the catch rates around Guam are <50 percent of the catch rates at most other banks, any shrimp fishing should target areas other than Guam. In the southern islands the best shrimp fishing areas are Saipan, Tinian, and Aguijan (Table 9). Although Galvez Banks and Santa Rosa Reef south of

[4]Reference to trade names or commercial firms does not imply endorsement by the National Marine Fisheries Service, NOAA.

[5]Moffitt, R. B., and J. J. Polovina. The distribution and yield assessment of the deepwater shrimp resource in the Marianas. Manuscr. in prep.

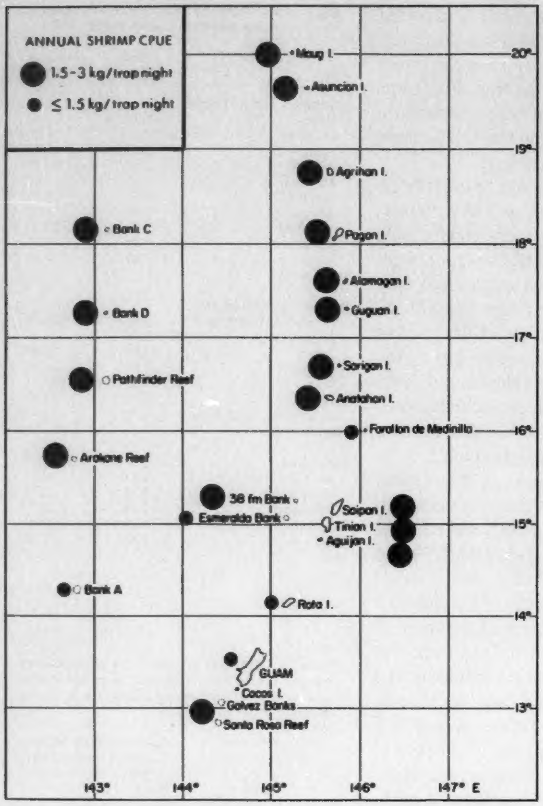

Figure 4.—Deepwater shrimp CPUE grouped into two catch levels.

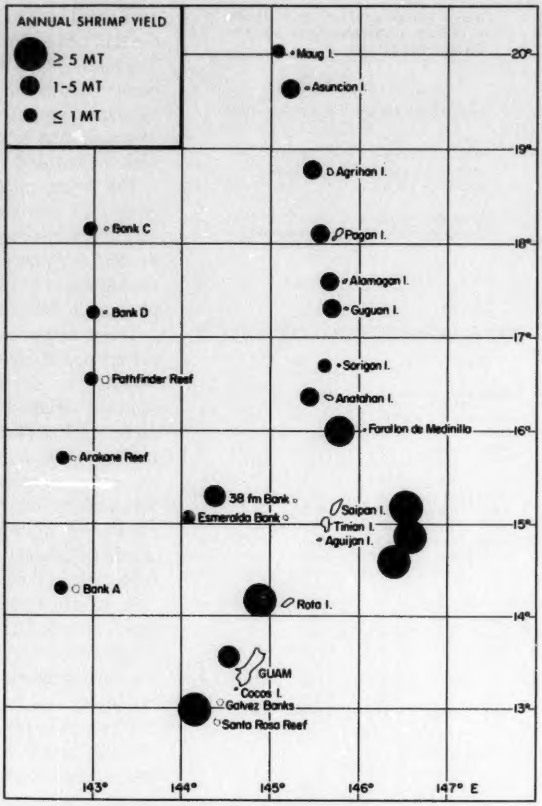

Figure 5.—Annual deepwater shrimp yield grouped into three yield levels.

Guam have good catch rates, the strong currents encountered there during the assessment work resulted in considerable trap loss.

The estimated catchability from the intensive trapping and the *F* of 0.5 correspond to an effort of 280 trap-nights/n.mi.^{2}. Given a total habitat of 800 n.mi.^{2} from 500 to 825 m, an annual effort of 224,000 trap-nights would produce the fishing mortality of 0.5 for the entire archipelago. Thus, for example, 28 small vessels which each set 40 traps/night for 200 nights/year would produce this effort and have an average fleet catch rate of 0.7 kg/trap-night and an average annual landing of 5.8 t/vessel.

Other Resources

There is a substantial resource of tunas and other pelagic species around the Marianas. The Japanese longline catch and effort data for the period 1965-79 and Japanese baitboat data for the period 1970-79 within 50 n.mi. and within the FCZ around Guam and the Commonwealth of the Northern Marianas have been analyzed by Polovina and Shippen[2]. The total annual tuna catches from Japanese longliners within the FCZ around Guam ranged from 9

Table 11.—Equilibrium yield for *Heterocarpus* spp. in the 500-825 m depth range.

Area	Yield[1]	Area	Yield[1]
Northern Islands and Banks		Saipan	54.1
		Tinian	16.3
Maug	0.9	Aguijan	7.8
Asuncion	1.5	Rota	24.7
Aguijan	3.0	Guam	3.9
Pagan	4.3	Galvez and	
Alamagan	3.0	Santa Rosa	20.2
Guguan	1.7	Subtotal	137.6
Sarigan	0.8		
Anatahan	3.1	Seamounts	
38-Fathom	1.7	Bank C	0.7
Esmeralda	0.3	Bank D	0.9
Subtotal	20.3	Pathfinder	0.9
		Arakane	0.5
Southern Islands		Bank A	0.6
and Banks		Subtotal	3.6
Farallon de			
Medinilla	10.6	Archipelago total =	161.5

[1]Metric tons/year based on a fishery mortality of 0.50.

to 1,334 t, and the annual catches within the FCZ around the Commonwealth of the Northern Mariana Islands ranged from 71 to 576 t. Billfish catches typically were about 10-30 percent of the total tuna catch. The total annual tuna catches from Japanese baitboats within the FCZ around Guam ranged from 83 to 2,059 t, and the catches within the FCZ around the Commonwealth of the Mariana Islands ranged from 2,554 to 12,564 t.

Annual catches of pelagic species typically from nearshore trolling, which include tunas, mahimahi, wahoo, and billfishes, are estimated at about 200 t for Guam and varied from 40 to 124 t for Saipan (Tables 6 and 7).

Although the Japanese catches indicate that the magnitude of the pelagic resource is large it is also widely dispersed. Fish aggregating devices are widely used throughout the Pacific and appear to be useful as a means of aggregating pelagic species and hence increasing catches, but the frequency of typhoons in the Marianas is an impediment to their application. The expansion of the charter fishing industry may have potential as a means of further exploiting the tuna and billfish resources, given the strong tourist industry in both Guam and Saipan.

Akule, often called atulai or bigeye scad, is a popular resource which is usually netted or hooked in nearshore areas. Reported annual landings in Guam and the Commonwealth of the Mariana Islands are only about 5 and 1 t, respectively, but much of the resource does not go through the usual market channels and is not reported. The RAIOMA Program found akule present at most of the islands and banks but, given the seasonal nature of the resource and effect of moon phase on the catch rates, a systematic survey was not possible. Two aerial surveys were not effective in estimating the nearshore akule biomass. The estimated catch rate of akule in the Hawaiian Islands from 1948 to 1982 varies from 0.4 to 0.9 t/n.mi. of 200 m contour. If it is assumed that abundance of akule in the Marianas is equivalent to that in Hawaii, then the Marianas, where the length of the 200 m contour is 490 n.mi., would offer a range of harvest from 200 to 440 t per year. However, most of the catches in Hawaii are by small purse seiners using aerial spotters, and these catches extrapolated to the Marianas may represent upper bounds for the more traditional gear.

Literature Cited

Beddington, J. R., and J. G. Cooke. 1983. The potential yield of fish stocks. FAO Fish. Tech. Pap. 242, 47 p.

Beverton, R. J., and S. J. Holt. 1956. A review of methods for estimating mortality rates in fish populations, with special reference to sources or bias in catch sampling. Rapp. P.-v. Reun. Cons. Int. Explor. Mer 140:67-83.

Gulland, J. A. 1983. Fish stock assessment. A manual of basic methods. John Wiley & Sons, N.Y., 223 p.

________. 1984. Advice on target fishery rates. ICLARM Fishbyte 2(1):8-11.

Polovina, J. J. In press. Variation of catch rates and species composition in handling catches of deepwater snappers and groupers in the Mariana Archipelago. Submitted to Proceedings of the 5th International Coral Reef Congress, Tahiti, 1985, Vol. 1.

________, and S. Ralston. In press. An approach to yield assessment for unexploited resources with application to snappers and groupers in the Marianas. Fish. Bull. (U.S.).

Ralston, S., and J. J. Polovina. 1982. A multispecies analysis of the commercial deep-sea handline fishery in Hawaii. Fish. Bull., U.S. 80:435-448.

A Small Vessel Technique for Tracking Pelagic Fish

KIM HOLLAND, RICHARD BRILL, SCOTT FERGUSON,
RANDOLPH CHANG, and REUBEN YOST

Introduction

The advent of ultrasonic telemetry techniques for monitoring fish movements in the wild has greatly increased our understanding of the behavior and physiological capabilities of pelagic fish (Carey, 1983). The development of pressure sensitive transmitters has allowed insights into the remarkable pressure (depth) and temperature tolerances of these animals while simultaneously revealing their fine-scale horizontal movements.

Previous tracking studies involving pelagic species have been carried out using large fishing or oceanographic research vessels. Because of the high operating costs of these vessels and the heavy demands on their time, comparatively few fish have been tracked. Also, the tracks that have been made come from widely scattered areas. Thus, although valuable data have been acquired from individuals of several species, only rarely have enough replicate tracks been obtained to give a reasonable indication of the normal daily behavior of a species in a particular location. Pelagic species that have been tracked include skipjack tuna, *Euthynnus pelamis* (Yuen, 1970); yellowfin tuna, *Thunnus albacares* (Carey and Olson, 1982); albacore, *T. alalunga* (Laurs et al., 1977); swordfish, *Xiphias gladius* (Carey and Robison, 1981); blue marlin, *Makaira nigricans* (Yuen et al., 1974); mackerel sharks (Carey et al., 1981); and Atlantic salmon, *Salmo salar* (Westerberg, 1982).

This paper reports on the development of a technique for using a small vessel for the ultrasonic tracking of pelagic fish. Our system produces high-resolution data and is sufficiently adaptable and cost-effective to allow prolonged tracking efforts in a variety of situations. Because of its modest cost, a small vessel can be dedicated to a tracking project for extended periods. This permits acquisition of many replicate multi-day tracks. Thus, sufficient amounts of data can be acquired to yield reliable information about the sequential daily behavior of a target species. Details of our system and methods have been included to allow other workers to adapt our techniques to their own needs.

The impetus for development of our tracking technique began when the Honolulu Laboratory of the National Marine Fisheries Service (NMFS) Southwest Fisheries Center pioneered the modern use of fish aggregating devices (FAD's) by deploying several of these buoys in Hawaiian waters in 1975 (Matsumoto et al., 1981). These deep-water FAD's have proved to be very effective and their use has spread throughout the Indo-Pacific (Shomura and Matsumoto, 1982). However, the influences of FAD's on fish behavior which result in the aggregation of pelagic fishes at these buoys are not understood. Given the importance of FAD's, the high costs associated with FAD deployment, and unanswered questions relating to stock harvesting and management, we initiated a project using ultrasonic transmitters and a small pursuit vessel to document the movements of pelagic species associated with FAD's. To date, our efforts have concentrated solely on yellowfin tuna and bigeye tuna, *T. obesus*, with fork lengths between 50 and 75 cm.

Methods

General

Our two major objectives when equipping the vessel were simplicity and redundancy. The data acquisition and recording systems were designed to emphasize shore-side data processing,

ABSTRACT—Tracking of pelagic fish has previously been conducted from large research or fishing vessels, both of which are expensive to operate. We have adapted advances in ultrasonic tracking technology to permit tracking of pelagic fish from a small (33-foot) vessel. Sportfishing techniques have been successfully employed to capture fish for tracking.

The use of a small vessel has many advantages including maneuverability in congested areas, the ability to work both offshore and close to shore, high responsiveness to changes in fish behavior, and low operating costs. Low operating costs allow the vessel to be utilized over extended periods, thereby permitting replication of experiments. High quality data on the vertical and horizontal movements of pelagic fish have been acquired for periods of up to 6 days. These techniques could be utilized to track fish inexpensively in a wide range of locations.

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thereby maximizing the use of on-board space and equipment for actual acquisition and storage of high-quality raw data. Secondary objectives were minimizing operating costs and maximizing crew comfort, thus improving our ability to track fish for long durations.

The Vessel

The R/V *Kaahele'ale* is a 33-foot vessel built for the U.S. Navy as a personnel boat. It was acquired by the NMFS in 1979 and modified for nearshore fisheries research, primarily telemetry. As modified, the vessel has an open-stern deck, a semi-enclosed central cabin with engine beneath, and a fully enclosed forward cabin. The stern deck is equipped for fishing and tagging. The central cabin houses the steering console and an instrument rack containing the telemetry equipment, navigation equipment, and radar. The forward cabin is air conditioned and contains two bunks, a work bench, an expendable bathythermograph (XBT) system, and a microwave oven.

The vessel is powered by a single screw driven by a GM-671[1] diesel engine through an Allison hydraulic transmission. Two 120-gallon fuel tanks are backed with a 50-gallon reserve tank. At cruising speed (11 knots), fuel consumption is 10 gallons/hour, at trolling speed (7.5 knots) it is 5 gallons/hour, and during tracking operations fuel consumption is usually less than 3 gallons/hour. The main engine alternator supplies a 24 volt main battery which powers the starter motor, the radar, and autopilot. Radios, tracking instrumentation, navigation lights, and fathometers are powered by a separate 12V DC battery bank. A 7.5 KW 120V AC diesel generator (Onan) is housed below a portion of the stern deck and powers the XBT system, the microwave oven, the forward cabin air conditioner, and an automatic 12V battery charger.

Tracking Apparatus

Transmitters

Pressure sensitive 50 KHz ultrasound transmitters were purchased from Vemco, Halifax, Nova Scotia. Two types of transmitters have been used, one with an expected operation life of up to 22 days and the other with nominal expected life of 3 days. We have found maximum open ocean operating ranges to be about 0.8 miles for the 3-day tags, and about 0.5 miles for the 22-day tags. The transmitters are pressure sensitive such that the pulse frequency of the 50 KHz carrier signal is directly proportional to increasing pressure (depth). Normal operating range is zero (surface) to 500 psi (370 m depth). The 22-day duration transmitters are cylindrical (8.0 cm long and 1.6 cm diameter) and weigh 27.7 g in air and 11.7 g in seawater. The 3-day duration transmitters are of similar specifications. The transmitters are equipped with magnetically operated reed switches for rapid activation and have a nylon loop at one end for use in attachment to the fish (discussed later).

Receivers

The 12V DC amplifier/receivers (CR-40, CAI Co.) are matched to the transmitters with 50 KHz crystal-controlled oscillators. These receivers amplify and convert the telemetered pulses into an audible signal. Two receivers were installed on the vessel in case one of the units failed during a track.

Hydrophone

The directional hydrophones were also manufactured by Vemco. However, a small but very significant modification was made after delivery from the factory. This modification involved the fabrication and installation of a 2 mm thick fiberglass faring over the leading face of the hydrophone (Fig. 1). This faring serves to protect the actual sensor from physical damage and, more importantly, reduces noise generated by water passing over the hydrophone. The signal/noise ratio is improved to such an extent that usable data can be acquired at boat speeds in excess of 7 knots. We can therefore track and acquire depth data from fast moving fish. The faring also allows the boat to be driven at 11 knots without damage to the hydrophone. No reduction in operating range

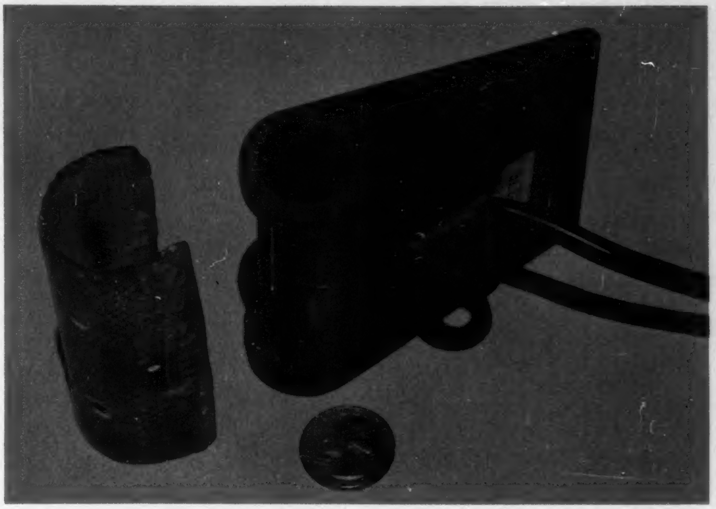

Figure 1.—The directional hydrophone is shown with fiberglass faring removed. Holes in the faring permit attachment to hydrophone body and allow water to flood the space between the hydrophone and the faring. The hydrophone sideplate has been removed to show hydrophone and preamplifier.

[1]Mention of trade names or commercial firms does not imply endorsement by the National Marine Fisheries Service, NOAA.

Figure 2.—Hydrophone Mounting. Top: The tracking hydrophone is in retracted position. Two triangular aluminum brackets mounted above the waterline allow the hydrophone to be lifted out of the water when not in use. Bottom: The hydrophone mounting pole is lowered through the support brackets to a position in which the hydrophone is clear of the keel and is unaffected by turbulence from the boat hull.

was observed following installation of the faring.

The hydrophone is braced within a stainless steel bracket bolted to the end of a 10-foot length of 1-inch I.D. galvanized pipe. The shielded cable from the hydrophone to the amplifier is threaded through the pipe. Shielding the cable is necessary to reduce radio frequency interference.

The hydrophone mounting pipe is deployed amidships using two triangular brackets, constructed of 1-inch I.D. aluminum tubing, which are bolted, one above the other, through the hull above the waterline. The pole is free to slide through the brackets and is held in place by thumbscrews. Thus, the hydrophone can be lowered for tracking and raised out of the water when not in use. This outrigger type of mounting allows the hydrophone to run about 5 feet below the surface and 6 feet to the side of the keel where it is unaffected by water turbulence generated by the hull (Fig. 2). During tracking, the hydrophone is secured facing forward in parallel with the keel of the boat, and localizing the transmitter (i.e., the fish) is accomplished by turning the vessel.

Depth Data Logging

A data processor/frequency counter (Telonics, TDP-2) is connected to the audio output of the receiver. This processor unit provides a digital display of the inter-pulse interval which is recorded manually at regular intervals and which gives an immediate indication of the fish depth and any changes in behavior. A cassette tape recorder is also connected to the audio output of the receiver. This provides a continuous record of the telemetered depth data for fine-scale plotting and analysis ashore.

Navigation

Three types of fixes are used to determine the vessel's position during tracking. The primary navigational reference is by Loran C (Furuno LC-80). This unit provides latitude and longitude in-

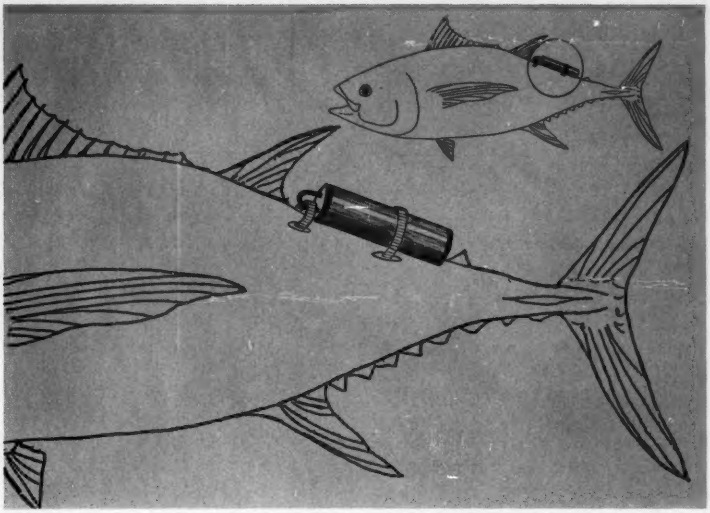

Figure 3.—The ultrasonic transmitter is attached to the dorsal surface using two nylon tiewraps inserted through the dorsal musculature and pterygiophores.

formation and also the vessel's course and speed. These latter data are useful in subsequent onshore analysis of the fine-scale movements of the fish. The waypoint storage capability of this unit also permits instantaneous information about the vessel's current position relative to starting or other important (e.g. FAD) positions. Supplementary visual fixes on charted landmarks are made using a hand-bearing compass or sextant. These visual fixes are made hourly to ensure the accuracy of the Loran C positions. The 24V DC radar unit is used to acquire accurate distances to landmarks or FAD's.

Oceanographic Information

Knowledge of the thermal structure of the ocean is essential to interpretation of the movements of the fish. Temperature data are acquired using a 110V AC expendable bathythermograph (XBT) system (Sippicon, Mass.). The XBT probes are deployed about every 3 hours or whenever the fish being followed moves into new waters (e.g., onshore to offshore). A bucket thermometer is used to verify the accuracy of the XBT surface temperatures.

Water current direction at FAD locations is determined by visual inspection of plastic streamers attached to the FAD's mooring chain. When operating in inshore areas (<100 fathoms) a fathometer is used to record ocean depth and to assist in determining geographic position.

Fishing and Tagging Techniques

The research vessel is equipped for both handline (drift) fishing and trolling. To date, most fish have been caught trolling. Artificial trolling lures tailored to the size of the target species are used with single "J"-type hooks. Large reels (14/0, Penn Reels, Pennsylvania) and 130-pound test line are used so that the fish can be reeled in rapidly to reduce capture stress. The reels are set with very light drag to reduce injury to the fish's mouth. After the initial strike and run, the drags are tightened and the fish brought to the boat as quickly as possible. Occasionally, the fish are towed behind the slowly moving vessel while the remaining fishing gear is retrieved and the stern deck prepared for tagging.

The tagging cradle is located in the center of the transom. The cradle is a foam-lined, "V"-shaped trough with one side hinged to allow variable gape to accommodate fish of different sizes. The fish to be tagged is lifted aboard, lightly wedged into the cradle and its eyes covered with a wet chamois cloth. These procedures are usually sufficient to immobilize the fish. Once aboard, species identification is verified, the hook removed, and mouth damage assessed and the fish length measured. Handling is performed without gloves which remove large amounts of mucus from the fish's surface.

Using the nylon loop embedded in one end of each transmitter, the unit is attached to the dorsal surface of the fish (adjacent to the second dorsal fin) using nylon "tie-wraps." These are inserted through the dorsal pterygiophores using sharpened hollow brass needles. Two tiewraps are used per fish; one passing through the transmitter loop, the other half way along the transmitter's length to prevent the transmitter from wobbling from side to side. After insertion through the musculature, the tie-wraps are cinched down and trimmed (Fig. 3). The fish is then released. The entire operation requires the fish to be on board between 1 and 2 minutes.

Tracking Techniques

Testing of the transmitter/receiver system has demonstrated that maximum operational range is between 0.25 and 0.8 n.mi., depending on the type of transmitter being used. Furthermore, we have established that maximum deflection of the signal amplitude meter on the CAI receiver occurs when the transmitter is within about 200 m of the vessel. Consequently, during tracking we attempt to keep the fish at just the distance where maximum gauge deflection occurs. This gives us added confidence in the accuracy of our tracks and also that we are not unduly "crowding" the fish. The directional hydrophone (and therefore the boat) is kept pointed at the fish by maximizing the audio output of the receiver. The small size of the vessel permits rapid changes of direction and rapid identification of the direction of the signal. Due to the noise reduction resulting from the installation of the

hydrophone faring, a fish can be pursued at up to 7 knots if it appears to be drawing away. At higher pursuit speeds depth data recording must be temporarily suspended because the noise of water rushing past the hydrophone masks the transmitter's signal.

Data Acquisition

During tracking, four types of data are acquired: 1) A continuous tape of fish-depth data from the audio output of the CAI receiver, 2) water depth/temperature profiles (XBT), 3) water depth, and 4) navigational data. Navigational data are recorded every 10 minutes and include: 1) Time, 2) heading/engine RPM, 3) Loran C fixes, and 4) visual and radar fixes (usually taken hourly). When close enough to a FAD, its range and bearing from the vessel are also recorded every 10 minutes. A narrative commentary is compiled to assist in subsequent data analysis.

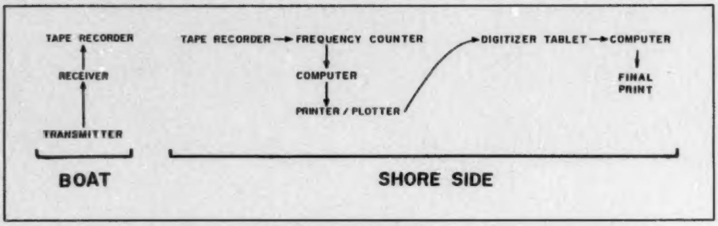

Figure 4.—Schematic representation of the data acquisition and analysis process.

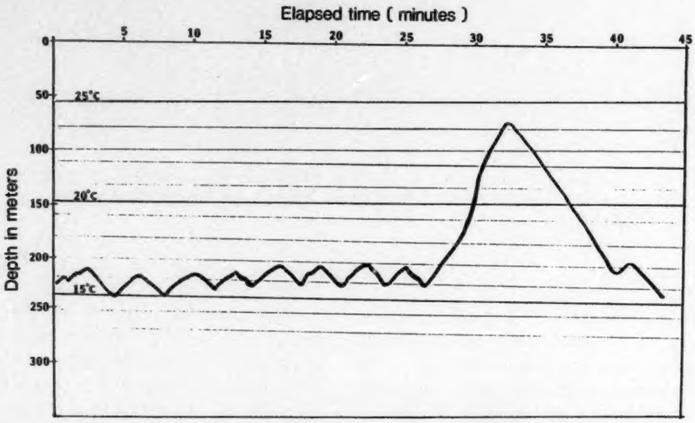

Figure 5.—A 45-minute vertical movement plot. Continuous recording of vertical movement data on cassette tapes allows both fine-scale and large phenomena to be discerned. Superimposing XBT data indicates that the swimming depth of this bigeye tuna is strongly influenced by the 15° and 17° C isotherms. Depth data of this type are recorded for the entire duration of each track.

Data Analysis

Vertical Data

Figure 4 summarizes the system for acquisition and analysis of vertical movement data. Once ashore, the recorded information is played from the cassettes into a Telonics TDP2 Data Processor. This processor is modified to output a +5V DC square wave each time a sound pulse is detected. A Hewlett Packard (HP) frequency counter (HP5308A) is used to time every other pulse interval. An HP 9845 computer with real-time clock converts the pulse intervals to depth and plots a graph of depth versus elapsed time. This original hard copy of the fish's swimming depth contains some erroneous points which are eliminated by tracing the depth-time profile on an Apple computer digitizer pad. This "cleaned" track (where depth is plotted every 10 seconds) is then stored on floppy disks prior to final plotting and analysis. Bathythermograph temperature profiles are superimposed on the final printouts (Fig. 5).

Horizontal (Position) Plotting

Because of the proximity of the tracking vessel to the target fish, no attempt is made to distinguish between the positions of the two. Plots are made on navigation and bathymetry charts based on Loran C positions recorded manually at sea. These relative positions are checked against the visual and radar fixes that were concurrently collected. Where applicable, fathometer readings are used as cross references for the other navigational data. Fine-scale movements of fish in the immediate vicinity of FAD's are plotted using manual records of the buoy's range and distance relative to the vessel.

Results

Since the installation of the tracking equipment in its current form, we have acquired 11 tracks of yellowfin tuna and 2 tracks of bigeye tuna that were caught near FAD's or near the adjacent coastline. The duration of the tracks ranged from 8 hours to 6 days.

All but one of the fish was caught by trolling. The small (6/0) size of hooks and light drag settings result in comparatively minor hook wounds. In only one instance has a fish died immediately upon release. All others have shown rapid recoveries to, what we believe, based on consistency within and across samples, is normal behavior. None of these tracks have been terminated due

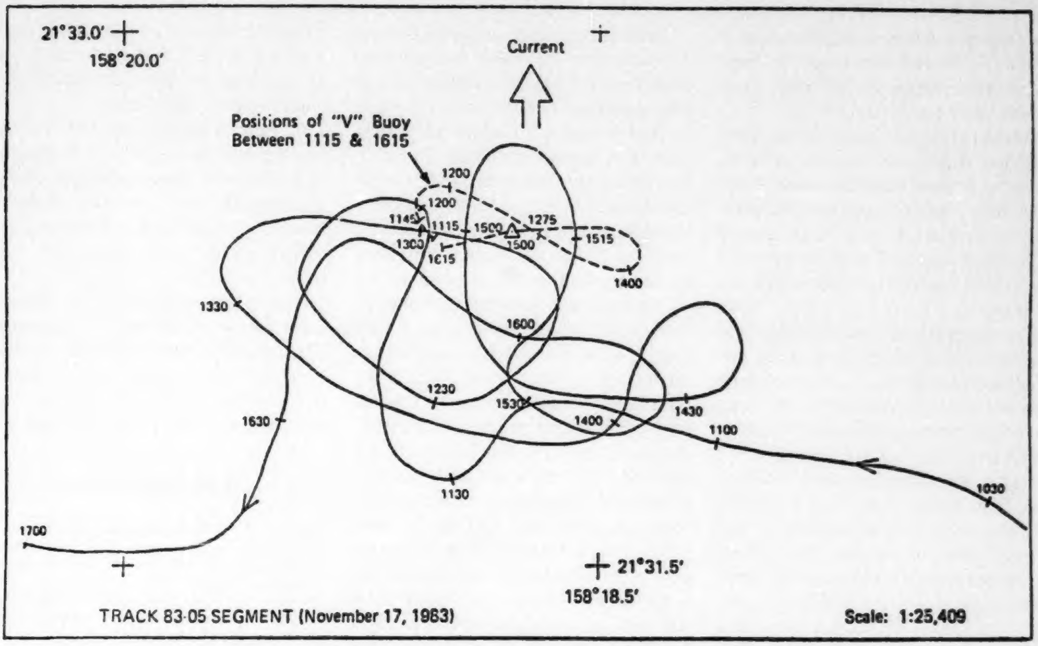

Figure 6.—Fine-scale horizontal plotting. Loran C, radar, and visual fixes allow fine-scale movements to be plotted. After arriving at FAD "V" off of Waianae, Oahu, this 55 cm yellowfin tuna spent about 85 percent of the next 5 hours on the upcurrent side of the buoy. The "Figure 8" movement of the buoy can also be plotted.

to death of the fish.

Captive fish tagged with the "double tie-wrap" method and observed in large tanks at the Kewalo Research Facility of the NMFS Honolulu Laboratory were able to swim normally with the school and appeared healthy after the 2-week observation period ended. In addition, a fortuitous recovery of a tagged fish by a fisherman attests to the suitability of our trolling/tagging technique. This fish was caught by a fisherman trolling near a FAD 3 weeks after we obtained a 36 hour track of it.

Discussion

Although almost all of the technology incorporated in the current research had been previously developed and utilized by others, we feel we have made significant advances in successfully adapting these techniques to a small vessel. Also, the ability to chase pelagic, highly mobile fish at 7 knots in the open ocean and still simultaneously collect vertical movement data is an innovation. We believe that our cassette recording and subsequent plotting of the vertical movement data has produced higher resolution vertical movement data than have previously been published. The continuous depth record has revealed phenomena (such as rapid vertical excursions and small scale oscillations) that manually collected data would have missed (Fig. 5). When the XBT data are superimposed on the tracks, much of the vertical behavior shows correlations with temperature (Fig. 5). Similar temperature influenced behaviors have been observed in bluefin tuna, *Thunnus thynnus* (Carey and Olsen, 1982).

The Loran C system of geographic plotting, when referenced with visual fixes, provides high resolution positioning of both large- and small-scale movements (Fig. 6). When Loran information is used in conjunction with visual fixes and radar ranges, small-scale movements of both the fish and FAD's can be plotted. Knowledge of the relationship between signal amplitude and transmitter distance lends confidence to the precision of the small-scale plots.

The small size of the tracking vessel has proved to have several advantages. For example, while able to pursue fish in the open ocean, the maneuverability of the vessel has also permitted unobtrusive data collection even when in the midst of many other vessels fishing at the FAD locations. Also, fish have been tracked to within 200 m of shore where larger vessels could not safely go. Similar situations occur in other locations such as straits, bays, lakes, and estuaries where tracking studies might be worthwhile but where large vessels would be too cumbersome. A vessel such as ours is capable of continuously following a fish both when it is moving in inshore (e.g., estuarine) waters and

also when it moves offshore where it would be beyond the range of fixed hydrophone arrays or of very small vessels such as skiffs.

Of course, small vessels are not suitable for mid-ocean work or offshore locations beyond refueling range. However, they could be used very successfully in association with a larger mother ship which could be performing other tasks while the small pursuit vessel was tracking.

The comparatively low hydrodynamic and mechanical noise generated by our small hull allowed the hydrophone to be attached directly to the side of the boat, thereby precluding the need for complex towed arrays such as have been deployed in some other tracking studies which used large vessels. Similarly, because a small vessel is very maneuverable and can accelerate quickly, the hydrophone can be permanently locked in an orientation parallel with the keel and the entire boat turned to accomplish maintaining contact with the target fish. This high responsiveness eliminates the need for rotatable or multi-head hydrophone systems such as have sometimes been used in the past.

Much of our tracking work has been conducted out of small boat harbors with depths of 2 fathoms or less and which would have been inaccessible to larger fishery research vessels. Each 24 hours of tracking consumes about 70 gallons of fuel. At this rate our vessel can track for at least 3 days without refueling, which can be conducted at any nearby small boat harbor. We have found crews of three sufficient for all phases of the field work. This, combined with the low fuel costs, makes the total operating cost of each tracking expedition extremely modest when compared with the $5,000 to $15,000 daily costs of large research vessels or commercial fishing boats. Our modest expenses enable the vessel to be dedicated to the tracking project for extended periods. This allows replicate tracks of different species from various locations. Also, because the vessel is committed to the tracking project full time, we can take advantage of short term increases in fish abundance and avoid fishing when fish are not abundant. Our ability to use sport fishing techniques to obtain fish for tracking indicates that labor-intensive trapping methods or expensive bait-boat techniques are not obligatory for a successful tracking program.

The small size and modular nature of the actual tracking equipment is such that it could be quickly installed on almost any suitable vessel. The major installation requirement is the bracing of the hydrophone brackets to the hull. However, since the bracket mountings are well above the water line, even this aspect of the installation could easily be repaired when the tracking is completed. The availability of an AC power generator has proved to be essential. Not only does this provide XBT capabilities but also allows improvement in crew facilities such as hot food and air conditioning.

The two major limitations of our system are fuel capacity and crew fatigue. We have solved the former by refuelling during prolonged tracks. However, this technique may be unique to our project because of the proximity of small boat harbors and the rhythmicity of behavior of some of our fish which has allowed us to relocate them after temporary suspension of tracking. Crew fatigue is inevitable with a small vessel after a few days on water. We feel that in our case this could be substantially remedied by using only a slightly larger vessel (e.g., 40-45 ft) which would be somewhat more spacious and comfortable and yet which would retain the desirable characteristics of maneuverability and low operating costs. Another possible technique would be the use of a shuttle vessel to exchange crews on the pursuit vessel.

We are currently unable to be completely sure whether or not the fish being tracked is travelling alone or in a school. We feel this shortcoming will be rectified by the installation of a chromoscopic fish finder.

In general terms, however, we feel that we have developed a cost-effective technique for acquiring high-quality tracking data which could be adapted to a range of small vessels operating in a variety of situations and locations. This, in turn, will result in a significant increase in our understanding of the normal behavior of commercially important fish species about which not much is currently known. Such an increase in our understanding will improve both management and fishing techniques.

Literature Cited

Carey, F. G. 1983. Experiments with free swimming fish, p. 57-68. *In* P. G. Brewer (editor), Oceanography, the present and the future. Springer-Verlag, N.Y.

Carey, F. G., J. M. Teal, and J. W. Kanwisher. 1981. Visceral temperatures of mackerel sharks. Physiol. Zool. 54:334-344.

Carey, F. G., and R. J. Olson. 1982. Sonic tracking experiments with tunas. Coll. Vol. Sci. Papers Int. Comm. Cons. Atlantic Tuna 17(2): 458-466.

Carey, F. G., and B. H. Robison. 1981. Daily patterns in the activities of swordfish, *Xiphias gladius*, observed by acoustic telemetry. Fish. Bull. (U.S.) 74(2):277-292.

Laurs, R. M., H. S. H. Yuen, and J. H. Johnson. 1977. Small-scale movements of albacore, *Thunnus alalunga*, in relation to ocean features as indicated by ultrasonic tracking and oceanographic sampling. Fish. Bull. 75(2):347-355.

Matsumoto, W. M., T. K. Kazama, and D. C. Aasted. 1981. Anchored fish aggregating devices in Hawaiian waters. Mar. Fish. Rev. 43(9):1-13.

Shomura, R. S., and W. M. Matsumoto. 1982. Structured flotsam as fish aggregating devices. NOAA-TM-NMFS-SWFC-22, 9 p.

Westerberg, H. 1982. Ultrasonic tracking of Atlantic salmon. I. Movements in coastal regions. Rep. Inst. Freshwater Res. Drottningholm 60: 81-101.

Yuen, H. S. H. 1970. Behavior of skipjack tuna, *Katsuwanus pelamis*, as determined by tracking with ultrasonic devices. J. Fish. Res. Board Can. 27(11):2071-2079.

Yuen, H. S. H., A. E. Dizon, and J. H. Uchiyama. 1974. Notes on the tracking of the Pacific Blue Marlin, *Makaira nigricans*, p. 265-268. *In* R. Shomura and F. Williams (editors), Proceedings of the International Billfish Symposium, Kailua-Kona, Hawaii, 9-12-72, Part 2. NOAA Tech. Rep. NMFS-SSRF 675.

Ice Requirements for Chilled Seawater Systems

E. KOLBE, C. CRAPO, and K. HILDERBRAND

Introduction

Chilled Seawater (CSW) is becoming increasingly popular in the United States for the preservation of fish aboard certain fishing vessels. Also called "slush ice" and "the champagne system," CSW has found recent application in several fisheries, many of which make use of portable tanks (200-2,000 l) aboard small inshore vessels (Dagbjartsson et al., 1982; Hansen, 1982; Eddie and Hopper, 1974). Larger-tanked CSW systems aboard seiners and transport vessels may be even more common (Kelman, Undated).

Canadian researchers and fishermen have done much to demonstrate and develop CSW on the North American Pacific coast. Flooded hold systems have, for several years, been used on Pacific salmon, *Oncorhynchus* spp., transport vessels (or "packers") in Canada and, more recently, on bottomfish draggers. Nearly all of these systems use air, bubbled into the tanks from a grid of pipes on the tank or fish-hold floor, to circulate cold water through the mass of newly-loaded fish[1]. This basic design is increasingly being used in the Alaska fishing industry.

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ABSTRACT—This paper describes an analytical approach to estimate ice quantities required by fishing vessels using slush ice or chilled seawater (CSW) systems. The calculations specify ice required for different values of hold size, catch volume, and time at sea, under varying conditions of water temperature, hold insulation, and hold flooding strategy. Observations and measurements recorded during four trips on three different steel salmon packers were used to verify the procedure and support several recommendations for CSW system operation.

Adequate ice is necessary to chill the fish and water that will eventually flood the hold (in most cases), and to maintain low temperatures during the trip. One rule of thumb is to first fill the tank or hold 1/3 full of ice, then flood to the top of the ice mass with water, and finally fill the tank with either fish or water (Dagbjartsson et al., 1982; Kelman, Undated).

Canadian researchers have suggested a formula[1] to aid in loading the correct tonnage of ice at the beginning of a trip. Commonly employed by U.S. CSW users, the "Canadian Formula," in short tons, is: *TONS OF ICE NEEDED* = (1/6) (*MW* + *MF* + *TIME*), where *MW* = tons of water to be chilled, *MF* = tons of fish to be chilled, and *TIME* = days duration of the trip.

In some cases the tank is first filled with water and ice as the vessel awaits the loading of fish; under most circumstances, a full hold is necessary for adequate vessel stability. Excess water then spills as fish are stowed in the tank. When operating in quiet water, a partially-filled tank may allow the operator to load less ice, dump no water, and completely fill the tank or hold only when it is time to begin the trip home. In these cases, the quantity of fish and water (*MW* + *MF*) is taken as the capacity of the tank in short tons.

The Canadian Formula enables a vessel operator to get a generally conservative estimate of ice needs for typical summer British Columbia conditions, assuming a well-insulated hold (Gibbard[2]). Subsequent experience then allows the fisherman to adjust ice tonnage to more closely match the needs as influenced by local conditions.

However, fishing conditions and CSW applications in Alaska or California may differ substantially from those in British Columbia. Many boats are inadequately insulated, thus requiring more ice due to heat leakage into the hold during a trip. Conversely, sea, air, and fish temperatures in Alaska, for example, may be lower during much of the fishing season, thus calling for less ice than necessary during summer months at lower latitudes.

This paper describes results of an analytical approach which enables one to project ice usage for CSW systems under a variety of circumstances. A series of algebraic equations coupled with appropriate simplifying assumptions has been described in a BASIC interactive program operable on a personal computer (see Appendix II). The procedure can evaluate the consequences of installing CSW without having adequately insulated the hold, estimate ice expense saved when high-quality insulation is installed, project ice use as environmental temperatures and fish volumes change, and, when conditions permit (e.g., aboard a docked processor vessel), investigate the effects of

[1]Chilled sea water system data sheet. Undated (ca. 1975). Technol. Res. Lab., Can. Dep. Fish. Oceans, Vancouver, B.C. Unpubl. manuscr.

[2]Gibbard, G. A. 1982. Personal commun. Formerly with Technol. Res. Lab., Can. Dep. Fish. Oceans, Vancouver, B.C.

operating at various fill-levels in the tank. A series of measurements aboard Alaskan salmon packers verified the analytical procedure.

Model Development

The total tonnage of ice needed during any fishing trip must be adequate to serve four purposes: 1) Chill the expected volume of fish, 2) absorb heat which leaks into the hold throughout the trip, 3) absorb heat resulting from the energy of bubbled air, and 4) chill seawater taken aboard—first to "slush" the ice (make a slurry into which fish can be dumped), and then to fill the hold to a predetermined level. In most cases, the hold is completely filled to eliminate the unbounded free water surface which can lead to capsizing of the vessel.

Ice Requirements for Fish and Water

The mass of ice needed to cool fish or water to the final holding temperature can be calculated from the following equation, written for the case of fish:

$$(MI_f)(L) = (MF)(C_{pf})(T_1 - T_2) \quad (1)$$

Where MF = mass of fish added,
C_{pf} = specific heat of fish,
MI_f = mass of ice which melts,
L = latent head of fusion for ice,
T_1 = initial temperature of water added to tank, and
T_2 = final temperature of the mixture.

The initial temperature of water added to the tank, T_1, would be the sea surface temperature. The final temperature, T_2, is the temperature of the CSW mixture, generally taken as −0.6°C (31°F), slightly below the ice-melt temperature of 0°C (32°F) due to the salinity.

Based on recent measurements aboard Oregon bottomfish trawlers, this is also a good approximation for the initial fish temperature prior to stowage in the CSW tanks. While tests showed that some fish recently brought from the ocean floor will be colder than the sea surface temperature, and that some lying on deck will be warmer due to solar and air heating, the average appeared to be close to the temperature of the sea surface.

Ice Requirements for Heat Leakage

The mass of ice required to absorb the heat which leaks into the slush-ice tank during the voyage can be calculated as:

$$(MI_l)(L) = (U)(A) \times (T_{out} - T_{in})(TIME) \quad (2)$$

Where MI_l = mass of ice which melts,
L = latent heat of fusion for ice,
U = an overall heat transfer coefficient,
A = the boundary area through which heat is transferred,
T_{out} = external ambient temperature,
T_{in} = temperature of the slush ice mixture,
$TIME$ = length of voyage.

The value for T_{out} is assumed to equal the sea surface temperature. This is based on documentation of weather data from regions of Atlantic Canada which indicated that for summer conditions, sea surface and air temperature averages were quite similar (Merritt et al.[3]), an assumption verified by measurements taken during the series of trips reported below. The analysis ignored the fact that engine room temperatures will be much warmer than those of the surrounding sea[4]. This is a reasonable simplification since the bulkhead separating the engine room from the fish hold constitutes only about 10 percent of the total boundary area[3] and is typically insulated more heavily than the other walls, floor, and deckhead.

The total boundary area can be expressed as a direct function of a cubic tank volume:

$$A = (6)\,(V)^{(2/3)} \quad (3)$$

Where A = the boundary area through which heat is transferred and
V = tank volume.

However, holds or tanks which are not cubic in shape would have a greater surface-to-volume ratio. Dimensions of fishing boat holds compiled by Merritt et al.[3] indicate that use of a coefficient of 7.2 (rather than 6) in Equation 3 better describes the typical case; it is the relationship used in this analysis.

The overall heat transfer coefficient U accounts for thermal resistance of the wall plus both inner and outer fluid films. However, resistances of the convective films in water and wind will be small compared with those of the wall sections and are thus neglected.

Our analysis has assumed three levels of insulation for the representative wall sections shown in Figure 1 for the side walls and bulkheads of a 30 m (100-foot) steel vessel (Hanson, 1960; Merritt et al.[3]). Note that the "RESISTANCE" value given for each level in Figure 1 is the reciprocal of the overall heat transfer coefficient U. Calculations to determine these resistance values followed two procedures: For "Level 1" and "Level 2" in which steel frames directly contact inner and outer boundaries, the "Zone Method" outlined by ASHRAE (1981); for "Level 3" in which insulation covers the ends of the steel frames, an empirical method described by Munton and Stott (1978).

Heat Load From Air Flow

To the quantity of heat leaking from the outside environment must be added the quantity of heat due to throttling of compressed air injected into the CSW mixture to effect circulation. This rate of heat addition is equivalent to the rate of energy supplied by the air pump.

The analysis first assumes the rate of air flow to be 0.152 m^3/minute (at 1 atm and 21°C) per square meter of deck-

[3]Merritt, J. H., E. Kolbe, and W. Robertson. 1983. Refrigerated storage of fish at sea with particular reference to thermal insulation. Unpubl. Res. Rep., Can. Inst. Fish. Technol. Tech. Univ. Nova Scotia, Halifax, 250 p.
[4]Measurements during recent trips on Oregon bottomfish trawlers indicated engine room air temperatures of 18-39°C (65-102°F).

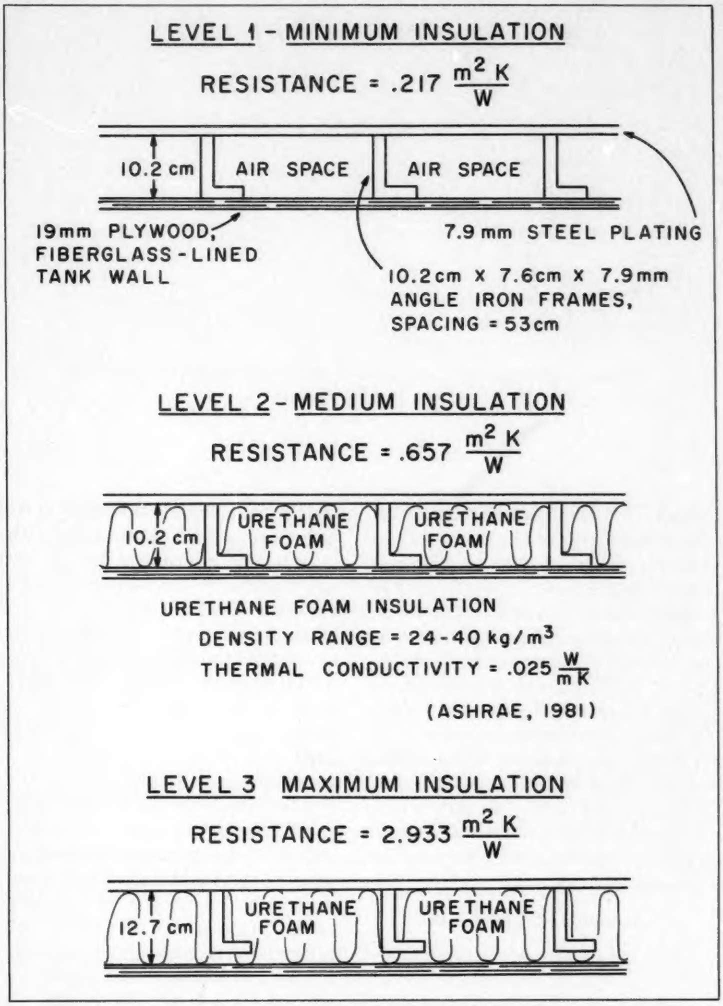

Figure 1.—Representative steel wall sections with calculated resistance values used in the analysis of ice consumption.

head (0.5 standard foot^3/minute per square foot of deckhead) following Canadian recommendations[1]. It next assumes deckhead area to be 30 percent of the boundary total, a figure representative for vessel lengths in the range of 25 m (80 feet)[3]. These assumptions with Equation 3 can then indicate volumetric flow rate of air injected into the CSW tank.

Air pressure required to overcome pipe friction and static head of water in the hold is typically 35-48 kPa gage (5-7 psig)[1]. Semi-empirical relationships (Baumeister and Marks, 1967) give power into the air based on the required flow rate and supply pressure. The entire rate of energy supplied is assumed dissipated in the CSW tank. As an example, the rate of ice melt due to bubbled air into a representative 30 m (100-foot) vessel having a hold volume of 176 m^3 (6,200 feet^3) will be on the order of 0.07 t/hour (0.08 short tons/hour).

Fill Strategies and Equation Development

As fish, water, and ice are added to the tank, the heat balances that match ice with heat sources are coupled with a volume balance to ensure that all necessary ingredients will fit into the tank. The analysis can select one of three cases for calculation: 1) Fill/Spill, 2) Fill/No-spill, or 3) No-fill/No-spill.

Fill/Spill

In the Fill/Spill case, the tank is first flooded to the top with water and ice. This ensures a stable vessel while operating in the open sea before fish are loaded. This case will require the greatest tonnage of ice because it must include a quantity to chill water that will be dumped later.

Fill/No-spill

In this case, water is initially filled to the level of the ice, creating a slush, after which fish are added. If the tank is not then full, more water plus the necessary extra ice is added until the tank is full.

No-fill/No-spill

In rare circumstances, such as in a docked or anchored processing vessel, tanks can safely remain partially filled. In this case, water is first filled to the level of the ice to create a slush, and then fish are added.

A summary of equations developed for each of these fill strategies appears in Appendix I.

Boundary Conditions

Throughout the calculation procedure, the program checks to ensure that certain boundary conditions are not exceeded. One check warns if the volume of the ice-water-fish mixture exceeds the total tank volume, a condition easily reached when loading excessive amounts of fish.

A second check warns if the volume of the bulk-loaded ice exceeds the tank

Table 1.—Specific volumes of loosely packed ice (from FAO, 1975; Merritt, 1978).

Type of ice	Specific volume
Flake	2.1-2.3 m^3/t (67-74 $feet^3$/short ton)
Tube	1.6-2.0 m^3/t (51-64 $feet^3$/short ton)
Plate	1.7-1.8 m^3/t (55-58 $feet^3$/short ton)
Crushed block	1.4-1.6 m^3/t (45-51 $feet^3$/short ton)

```
THIS IS 'SLUSH', A PROGRAM TO CALCULATE ICE REQUIREMENTS FOR CSW TANKED SYSTEMS


CASE  2  FILL/NO-SPILL

                    *****
 TANK CAPACITY IS INADEQUATE TO HOLD ALL THE FISH REQUIRED.
  THE PROGRAM HAS DECREASED THE INPUT AMOUNT OF FISH TO BE LOADED.
                    *****
INITIAL TEMPERATURE              56 F
TANK VOLUME                      1152 CUBIC FEET
FISH TO BE LOADED                21.3 TONS
NUMBER OF DAYS TO BE HELD        2 DAYS
HOURS PER DAY OF AIR BUBBLING    2 HOURS
ASSUMED INSULATION LEVEL         MIN
ICE MELT FROM FISH               3.1 TONS
ICE MELT FROM HEAT LEAK          2.7 TONS
ICE MELT FROM BUBBLED AIR        0.1 TONS
ICE MELT FROM WATER ADDED         1.2 TONS
TOTAL ICE REQUIRED                7.2 TONS
APPROX PERCENTAGE OF TANK
  OCCUPIED BY DRY
  BULK-LOADED ICE                42
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Figure 2.—Sample output, representing the ice required for the center hold of Trip 4 (Table 4).

volume even before fish are added to the tank. Specific volumes (volume per unit mass) are given in Table 1 for various types of ice. Excessive ice volumes can occur when trips are long, tanks are small (and thus have high surface-to-volume ratios), and when insulation is poor. Even if bulk ice volume does not exceed the tank volume, there may be problems if so much ice were carried that inadequate space remained to initially load a large volume of fish. The program issues a warning if bulk ice volume exceeds 90 percent of the tank volume.

Because an adequate chill rate of the fish will be achieved only if the bubbled air-driven cold water can circulate, a third check is on the fish packing density. If this is too great, it will prevent adequate cold water circulation throughout the entire load. This analysis assumes a maximum permitted fish loading density of 670 kg/m^3 (42 pounds/$foot^3$), a value found by National Marine Fisheries Service researchers to be valid for small tanks[5]. This is slightly lower than the value of 720 kg/m^3 (45 pounds/$foot^3$) given by Gibbard and Roach (1976) for refrigerated seawater systems and used for large-tanked CSW systems as well[2,6].

Calculation of Results

The analytical procedures describing ice required under various conditions and loading strategies have been written as a BASIC computer program (Appendix II). Using thermodynamic values from ASHRAE (1981, 1982), and assuming the use of flake ice (Table 1), the program allows the user to select insulation level, loading strategy, and other operating parameters to generate an output similar to that shown in Figure 2. In this example, an attempt was made to input 22.5 short tons (20.4 t) of fish to simulate the loading rate observed during a summer trip in Alaskan waters. Because this exceeded the allowed packing density, the program has adjusted the fish tonnage to maximum capacity and has printed an appropriate message.

Methods and Materials

Four trips were made during summer 1984 on three CSW salmon packers operating out of Kodiak, Alaska. These trips provided opportunities to observe procedures, estimate ice use rates, and measure significant temperatures and chill rates aboard vessels having different levels of insulation. These data allow a comparison of observed ice requirements with those predicted using the calculations described.

Temperatures were recorded manually using a YSI Telethermometer Model 42-SC (Yellow Springs Instrument Co.[7]). Typically, an array of nine thermistor sensing probes was placed in fish and water as loading proceeded. The quantity of ice loaded at the trip start was reported by the supplier of ice to the vessel. The ice remaining at the end of the trip was an estimate based on the number of totes (boxes) filled with unmelted ice plus, in some cases, judgement of the vessel operator on the amount left aboard after draining the tanks.

All three vessels had commercially installed air blower and distribution systems layed out in general agreement with Canadian recommendations[1]. All travelled to areas having relatively quiet water before loading fish; all ended trips by first draining tanks before returning to home port through unsheltered water. The vessels differed in hold size, layout, and insulation characteristics, and general description of each is given in Table 2.

Results

Ice use rates, as well as data influencing these rates, recorded during the four trips at sea appear in Table 3.

The schedule of air circulation was similar for each vessel and trip. Air blowers typically operated for 20-30 minutes when the tank was first flooded with water, then for about 10 minutes each time a load of fish was added from a catcher vessel. Total air pumping time ranged from 1 to 3 hours per day. (This

[5]Collins, J. 1983. Personal commun. Formerly with Utilization Res. Lab., Northwest Alaska Fish. Cent., Natl. Mar. Fish. Serv., NOAA, Kodiak, Alaska.

[6]Lee, F. 1982. Personal commun. Formerly with Technol. Res. Lab., Can. Dep. Fish. Oceans, Vancouver, B.C.

[7]Mention of trade names or commercial firms does not imply endorsement by the National Marine Fisheries Service, NOAA.

Table 2.—Characteristics of vessels A-C used in trips 1-4.

Vessel	Trip no.	Length m	Length feet	Tanked hold volume m³	Tanked hold volume feet³	Tank layout	Insulation[1]
A	1, 2	22	75	86	3,037	Fiberglass partitions or bin boards separated one hold into smaller compartments, each approximately 2.1 m (7 feet) high, and each having air supply pipes on the floor.	20 cm (8 inches) of urethane foam on sides, floor, lazaret bulkhead, and deckhead; 30 cm (12 inches) of urethane foam on the engine room bulkhead. Insulation under center floor sump is unknown.
B	3	25	82	90.9	3,200	Bin boards to a height of 1.2 m (4 feet) from the floor separate one hold into smaller sections.	15 cm (6 inches) of urethane foam on all boundaries, including area under center sump.
C	4	22	75	[2]32.6 [3]32.6 [4]29.0	[2]1,152 [3]1,152 [4]1,024	Each of three holds is separate from the other. None of the holds had separating boards or partitions.	Except for tank liner and enclosed air space there was no insulation on boundaries of the forward and center holds. Boundaries of the aft hold had 15 cm (6 inches) of urethane foam.

[1]As reported by vessel operator.
[2]Forward hold—not loaded with fish.
[3]Center hold.
[4]Aft hold.

Table 3.—Observations during four trips at sea.

Item	Trip no. and vessel (letter) 1 A	2 A	3 B	4 C Forward hold	4 C Center hold	4 C Aft hold
Trip length, days	3	2	1.5		2	
Avg. SST (°C)	12.8	11.7	12.2		12.8-13.3	
Avg. air temp. (°C)	12.8	12.8	13.3		12.2-18.3	
Core temp. of several fish before loading (°C)	13.3-15.6	12.8-15.0	13.3-16.7		12.8-16.7	
Fish loaded (t)	22.7	26.8	51.8	0	20.5	8.6
Ice loaded (t)	13.9	9.1	16.4	8.2	8.2	7.3
Est. ice remaining at trip's end (t)	5.5-6.4	2.7-3.6	5.5-6.4	0	1.8-2.7	3.6
Est. ice used (t)	7.5-8.4	5.5-6.4	10.0-10.9	8.2	5.5-6.4	3.6
Fill level of tank after loading (%)	60	60	100		100	80

Table 4.—Recorded and calculated ice use rates.

Trip no. and vessel (letter)	Recorded values: Ice used (t)	Recorded values: Fill level after loading (%)	Computer Calculations: Fill level after loading (%)	Computer Calculations: Ice used (t)	Computer Calculations: Assumed insulation level (Fig. 1)	Calculations from Canadian formula: Fill level after loading (%)	Calculations from Canadian formula: Ice used (t)
1(A)	7.5-8.4	60	42	6.8	Medium	100	15.2
			60	[1]8.1			
2(A)	5.5-6.4	60	46	6.1	Medium	100	15.0
			60	[1]7.4			
3(B)	10.0-10.9	100	100	11.8	Maximum	100	15.7
			100	[1]11.0			
4(C)							
Fwd. hold	8.2		19	3.0	Minimum	100	5.9
Ctr. hold	5.5-6.4	100	100	6.6	Minimum	100	5.9
Aft hold	3.6	80	47	2.6	Medium	100	5.3
			80	[1]3.3			

[1]Corrected value.

period of air bubbling is shorter than that generally recommended from the Canadian experience[2,8]). Additional observations specific to individual trips are given below.

Trip 1

The 15 compartments within the hold of Vessel A were not initially filled with equal quantities of ice. Several had no ice remaining at the end of the trip, although CSW temperatures appeared to stay close to 0°C (32°F) owing to water circulation between compartments.

Trip 2

The loading and air pumping schedule for Vessal A was similar to that for Trip 1. Before the start of this trip, the vessel operator separated the bin boards slightly, enabling better circulation of cold water between the 15 compartments. This improvement, plus better initial ice distribution, led to unmelted ice remaining in each compartment at trip's end.

Trip 4

Vessel C's uninsulated forward hold, not loaded with fish, had no temperature probes so meltwater temperature at trip's end was unknown. Both fish and ice were poorly distributed in the center and aft tanks. Although some ice remained in the center tank at trip's end, it was all massed at one corner. Also, a small volume of chilled water was dumped from the center tank as the final fish loading took place. Temperatures in both tanks holding fish (center and aft) were uneven throughout the trip.

Comparisons

Table 4 compares recorded ice use rates with values calculated both with the analysis described above and with the Canadian formula. In addition to the influencing conditions reported above and data given in Table 3, the analysis used bulk ice volumes for flake ice, and an air pumping schedule of 2 hours per day.

The analysis for the case of partially-

[8]Operation of "Champagne" systems. Tech. Inf. Bull. 80-1 (unpubl.). Technol. Serv. Branch, Dep. Fish. Oceans, Environ. Can. 5 August 1980.

filled tanks (No-fill/No-spill) assumes fish to be loaded at the maximum allowable density, or minimum volume of water and ice. However for trips 1, 2, and 4 (aft hold), the operator loaded more ice and more seawater than necessary to achieve this maximum density, thus filling the tank fuller than the calculations would indicate. If the calculated "Fill level after loading" is corrected to match observed levels by adding seawater and the necessary extra ice to chill it down, the results (Table 4) allow comparison of calculated values ("corrected") with observed values at the same tank fill level.

Similarly, the analysis for the filled tank of trip 3 assumed that no unmelted ice remained at the end of the trip. In fact, unmelted ice did remain, occupying a volume that the analysis assumed was occupied by chilled water. The corrected value shown (Table 4) resulted from subtracting the amount of ice required to chill a volume of water occupied by the observed excess ice.

Discussion

Perhaps the greatest uncertainty in calculating ice consumption lies in estimating the heat which leaks into the hold during a trip. This is because these calculations depend strongly on several factors which may be unknown by the vessel operator—perhaps the second or third owner of the vessel—or which are highly variable during a trip. Examples include:

1) Nature of the fish hold boundary structure (e.g., frame spacing; connections between hold liner and frames; presence and thickness of concrete floor; deck covering; nature of penetrating structure like piping, manholes, and stanchions) and type, thickness, quality, or existence of insulation;

2) Nature and degree of separation of adjacent compartments (e.g., warm fuel tanks or net lockers, hot engine room, additional cold CSW tanks);

3) Area of the hold or tank boundary;

4) Level to which the flooded CSW tank is filled;

5) External heat transfer film coefficients—generally low and variable with wind speed if in air, and high if the surface is hit by spray or is below the waterline;

6) External sea temperature and air temperature which may vary from day to day or from day to night; and

7) Solar load on the deck or wall of the vessel.

Despite these uncertainties and the approximate nature of some observations documented in Table 3, the prediction of ice consumption shown in Table 4 for these documented trips at sea are close to recorded values. The predicted consumption in the uninsulated forward hold of Trip 4 shows the poorest agreement with the observed result. This hold, which was unused, uninsulated, and adjacent to the engine room, obviously had much worse heat leakage rates than what was described using the resistance value for the "minimum" level of Figure 1. Structural penetrations and an uninsulated shaft tunnel could account for most of this difference.

Although good insulation was reported by the operator of vessel A (Trips 1 and 2), the use of "medium" rather than "maximum" insulation resistance (Fig. 1) provided a closer calculation of the ice consumption rate. Again, undocumented structural penetrations would have decreased the effective boundary thermal resistance.

As shown by Table 4, the Canadian Formula did not match observed results well at all. This was expected because it was not intended for these situations.

The example calculation of Figure 2 presents values (in British units) corresponding to ice consumption in the center hold of Trip 4 and gives relative quantities for the different heat sources. With the short air bubbling periods experienced on these trips, expected ice consumption due to injected air is minor.

For most calculations using the "maximum" insulation level, ice consumption due to heat leakage is a minor fraction of the total. It is with less efficient insulation, as considered in the example of Figure 2, that heat leakage becomes significant and uncertainties more important. Research to gain a better understanding of thermal resistances of fish hold boundaries is presently underway at the Department of Agricultural Engineering, Oregon State University, Corvallis.

Acknowledgments

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Literature Cited

ASHRAE. 1981. Handbook of fundamentals. Am. Soc. Heating, Refrigerating, Air Conditioning Engr., Atlanta, Ga., 926 p.

________. 1982. Handbook of applications. Am. Soc. Heating, Refrigerating, Air Conditioning Engr., Atlanta, Ga., 706 p.

Baumeister, T., and L. S. Marks (editors). 1967. Standard handbook for mechanical engineers. McGraw-Hill, N.Y., seventh ed.

Dagbjartsson, B., G. Valdimarsson, S. Arason. 1982. Icelandic experience in storing fish in chilled seawater, p. 233-242. *In* Advances in the refrigerated treatment of fish. Proc. Int. Inst. Refrig. Conf., Boston.

Eddie, G. C., and A. G. Hopper. 1974. Containerized stowage on fishing vessels using chilled sea water colling, p. 69-74. *In* R. Kreuzer (editor), Fishery products. Fish. News Books Ltd., Surrey, Engl.

FAO. 1975. Ice in fisheries. FAO Fish. Rep. 59, Rev. 1, 57 p. Food Agric. Organ., U.N., Rome.

Gibbard, G. A., and S. W. Roach. 1976. Standards for an R.S.W. system. Environ. Can., Fish. Mar. Serv. Tech. Rep. 676, Vancouver, B.C., 12 p.

Hansen, P. 1982. Containers for chilling, stowage and transport of fresh fish in ice water, p. 251-258. *In* Advances in the refrigerated treatment of fish. Proc. Int. Inst. Refrig. Conf. Boston.

Hanson, H. C. 1960. Steel and wood scantling tables (west coast of USA), p. 137-145. *In* J. Traung (editor), Fishing boats of the world, vol. 2. Fish. News (Books) Ltd. Lond.

Kelman, J. H. Undated. Stowage of fish in chilled sea water. Torry Advisory Note 73, 10 p.

Merritt, J. H. 1978. Refrigeration on fishing vessels. Fish. News Books Ltd., Farnham, Surrey, Engl. Rev. ed., 161 p.

Munton, R., and J. R. Stott. 1978. Refrigeration at sea. Second ed., Appl. Sci. Publ. Ltd., Lond., 238 p.

Appendix I

Relationships for the mass of ice required to chill fish and to absorb heat leakage from the warm sea and air ambient are presented in Equations (1) and (2) respectively. The mass of ice required to absorb the energy of bubbled air is represented by the following equation:

$$MI_a = (0.08)(V/6{,}200)^{2/3}(TIME)(TAIR) \qquad (4)$$

where 0.08 = ice consumption rate (in short tons/hour) in a typical 30 m (100-foot) vessel; and 6,200 = a typical hold volume (in feet ^{3}) of the same vessel. Other symbols are defined in Appendix Table 1.

The additional ice required to absorb the heat of added seawater while occupying the available volume in the tank, depends upon the fill strategy, as outlined in the report. The additional equations corresponding to these fill strategies appear below.

Appendix Table 1.—Symbols used in Equations (4) through (7).

C_{pw}	=	Specific heat of seawater.
L	=	Latent heat of fusion of ice.
MF	=	Mass of fish.
MI_a	=	Mass of ice required to absorb bubbled air energy.
MI_f	=	Mass of ice required to cool stowed fish.
MI_l	=	Mass of ice required to absorb heat leakage.
MI_w	=	Mass of ice required to cool added water.
T_1	=	Initial temperature of fish or water before stowage.
T_2	=	Final temperature of fish and water in CSW tank.
$TAIR$	=	Hours per day that air is pumped.
$TIME$	=	Duration of holding period in CSW tank.
v_i	=	Specific volume of bulk loaded ice (see text Table 1).
V	=	Tank or hold volume.
VP	=	Partial volume occupied by fish/ice/water mixture in the "Fill/No-spill" and "No-fill/No-spill" cases.
ρ_i	=	Density of ice particles.
ρ_w	=	Density of seawater.
ρ_f	=	Average density of fish flesh.

Fill/Spill

The mass of ice required to chill water originally added to flood the tank is given by:

$$MI_w = V\left[\frac{\rho_i - (MI_l + MI_a + MI_f)/V}{1 + (\rho_i/\rho_w)\left[\dfrac{L}{C_{pw}(T_1 - T_2)}\right]}\right] \qquad (5)$$

Fill/No-spill

In this case the volume occupied by anticipated ice, water, and fish is first calculated by Equation (6). The computer routine adjusts quantities up or down to achieve a balance. The ice required for added water then results from Equation (7).

$$VP = \frac{v_i(MI_l + MI_a + MI_f)L}{L + (\rho_w/\rho_i)C_{pw}(T_1 - T_2) - v_i\rho_w C_{pw}(T_1 - T_2)} + \frac{MF}{\rho_f} \qquad (6)$$

$$MI_w = \left[\frac{\rho_w C_{pw}\rho_i(T_1 - T_2)}{\rho_i L + \rho_w C_{pw}(T_1 - T_2)}\right]\left[VP - (MI_f + MI_l + MI_a)/\rho_i\right] \qquad (7)$$

No-fill/No-spill

An estimated volume is first calculated using Equation (6); ice quantity for added water follows from Equation (7). But for this case, there is no concern to balance the volume to completely fill the tank.

Appendix II

This Appendix describes "SLUSH," a computer program which calculates ice required in chilled seawater (or slush ice) fish holding systems.

Holding fish in flooded-tank chilled seawater (CSW) systems provides several benefits. One is elimination of the need to shovel and distribute ice through the volume of bulk-loaded fish. Another is enabling rapid chilling of fish, especially significiant when large catches are brought aboard. A third is providing buoyancy to the fish and thus avoiding crushing that can occur in bulk-loaded iced fish systems.

Several conditions affect the success of these CSW systems. One is that the operator be aware of the vessel instability risks associated with partially-filled tanks. Another is that the bubbled air system normally used to bring about adequate circulation of cold water through the newly-loaded fish be properly designed and installed. And a third condition is that the operator use sufficient ice and avoid overloading the tanks with fish. Use of program SLUSH addresses this last condition and enables the user to learn how predicted ice consumption will vary with:

1) Fish hold or tank volume,
2) level of insulation in the boundaries,
3) filling strategy (whether the tank will be full or partially full),
4) seawater temperature,
5) amount of fish to be loaded,
6) length of time fish is to be held, and
7) length of time air is bubbled into the tank.

The program in BASIC language appears as Appendix Table 2 at the end of this section. It is "interactive," which means that the user enters information in response to questions which appear on the screen, and it requires a printer, since output appears both on screen and on printer. Input and output values are expressed in British ("Inch-Pound") units.

Program Operation

To operate the program, the user must enter information in response to requests appearing on the screen. The requests with required information are:

OCEAN TEMPERATURE (in °F). The expected sea surface temperature describes not only the warm seawater that will be chilled by ice in the hold, but also the approximate temperature of fish to be chilled.

HOLD OR TANK VOLUME (in feet^3).

NUMBER OF DAYS ICE WILL BE IN THE TANK.

NUMBER OF HOURS PER DAY BUBBLED AIR IS TO CIRCULATE.

CASE NUMBER TO BE CALCULATED, where
CASE 1 IS FOR FILL/SPILL,
CASE 2 IS FOR FILL/NO-SPILL,
CASE 3 IS FOR NO-FILL/NO-SPILL.
FILL/SPILL refers to a tank that is first filled to the top with sea water and ice before any fish are loaded aboard. This is the usual case where vessel stability dictates that the tank must remain full at all times. As fish are loaded, cold water is spilled—overboard or to another tank.
FILL/NO-SPILL refers to a tank that is loaded with fish, water, and ice in such a way that the tank is full at the end of loading. In this case a partially-filled tank is tolerated during loading; no cold water is spilled.
NO-FILL/NO-SPILL refers to a tank that can be filled to whatever level is necessary to exceed the minimum allowed fish loading density—considered by the program to be 670 kg/m^3 (42 pounds/foot^3).

INSULATION DESCRIPTION AS MIN, MED, OR MAX, where
'MIN' DESCRIBES A TANK HAVING ESSENTIALLY NO ("minimum") INSULATION,
'MED' DESCRIBES A MARGINALLY ("medium") INSULATED TANK, and
'MAX' DESCRIBES A WELL-INSULATED ("maximum") TANK.
The levels represented by these three descriptors appear in Figure 1 in the main text. Values of *U*, the overall heat transfer coefficient, were calculated for typical bulkhead and sidewall construction of a 30 m (100-foot vessel).

TONS OF FISH TO BE ADDED TO THIS CSW TANK.

Program Output

For each case, program output will appear on the printout sheet; Figure 2 in the main text presents an example of this output.

During calculation, the program checks to see that certain limits are not exceeded, and if they are, issues a warning. These warnings include the following:

WARNING: FISH LOADING DENSITY EXCEEDS MAXIMUM ALLOWED VALUE OF 42 LBM/FT3. TRY LOADING LESS FISH.

Experience has shown that filling the tank more than about two-thirds full of fish will prevent the bubbled air from promoting adequate water circulation. The result is that fish in the center are too slowly chilled. If the user enters an excessive mass of fish for the tank, the program will print the above warning on the screen and then await a new value of "TONS OF FISH TO BE ADDED".

WARNING: INITIAL BULK ICE VOLUME EXCEEDS TANK VOLUME BY — %. TRY BETTER INSULATION OR LESS FISH.

In a few circumstances of small tanks, poor insulation, or overloading, calculations indicate a required amount of ice having a bulk volume which is simply greater than the volume of the tank. When this happens, the above warning (or one similar, depending on the fill strategy being considered) appears on the screen, then returns to await new values of insulation level and fish. The program presently assumes the use of "flake ice" having a specific volume of 2.1 m^3/t (67 feet^3/short ton).

WARNING: INITIAL BULK ICE

VOLUME EXCEEDS 90% OF TANK VOLUME. MAY HAVE DIFFICULTY LOADING INITIAL CATCH.

This message, which appears on the printer for Case 1 (FILL/SPILL) warns if the initially-loaded ice exceeds 90 percent of the volume (but occupies less than the full tank volume). If this occurs, the crew will have difficulty loading fish until sufficient ice melts to provide the space. The program does not return for new input in this case, but continues on; the message appears with the printed output.

TANK CAPACITY IS INADEQUATE TO HOLD ALL THE FISH REQUIRED. THE PROGRAM HAS DECREASED THE INPUT AMOUNT OF FISH TO BE LOADED.

Calculations in Case 2 (FILL/NO-SPILL) automatically balance either the volume of fish or the amount of added water to arrive at a full tank. If the amount of fish was automatically decreased, the above printed message appears with the output of Case 2. If water (plus the required ice) is added to arrive at a full tank, the following message appears with the printed output: EXTRA WATER HAS BEEN ADDED TO FILL THE TANK.

PROGRAM HAS ADDED EXTRA WATER AND ICE TO REDUCE FISH PACKING DENSITY TO AN ACCEPTABLE VALUE.

The amount of water initially used in calculations for Case 3 (NO-FILL/NO-SPILL) has a volume equal to the voids within the bulk ice—that is, the water is filled to the level of the ice. If the volume of fish loaded exceeds the maximum loading density of 670 kg/m^3 (42 pounds/$feet^3$) in this partially-filled tank, the program adds more water (plus ice to chill it), and prints the above message with the calculation results.

Appendix Table 2.—Program listing.

```
10   'PROGRAM SLUSH   VERSION   7/1/85
30   'THIS PROGRAM CALCULATES ICE REQUIREMENTS IN CSW TANKS
40   '          E. KOLBE
50   '          OREGON STATE UNIVERSITY
60   '          SEA GRANT EXTENSION
70   'Begin program by defining variables that are unlikely to change.
71   'Note that all quantities are in British units.
80   CF     = .85  'Specific heat of fish
90   CW     = .964 'Specific heat of sea water
100  LI     = 144  'Latent heat of fusion of ice
110  RHOW   = 64   'Density of seawater
120  RHOI   = 57.5 'Density of ice
130  RHOF   = 64   'Density of fish
140  MIN    = .811 'Thermal transmittance for uninsulated wall, Btu/hr-ft2-F
150  MED    = .268 'Thermal transmittance for partiallly
160                'insulated wall, Btu/hr-ft2-F
170  MAX    = .06  'Thermal transmittance for well-insulated wall (Btu/hr-ft2-F)
180  CLS
190  PRINT "THIS IS 'SLUSH', A PROGRAM TO CALCULATE ICE REQUIREMENTS FOR
     CSW TANKED SYSTEMS"
200  LPRINT
210  LPRINT
220  LPRINT "THIS IS 'SLUSH', A PROGRAM TO CALCULATE ICE REQUIREMENTS
     FOR CSW TANKED SYSTEMS"
230  PRINT
240  PRINT "SPECIFIC HEAT OF FISH             ";CF;"BTU/LBM-F"
250  PRINT "SPECIFIC HEAT OF SEA WATER        ";CW;"BTU/LBM-F"
260  PRINT "HEAT OF FUSION OF ICE             ";LI;"BTU/LBM"
270  PRINT "DENSITY OF SEAWATER               ";RHOW;"LBM/FT3"
280  PRINT "DENSITY OF ICE                    ";RHOI;"LBM/FT3"
290  PRINT "DENSITY OF FISH                   ";RHOF;LBM/FT3"
300  PRINT "THERMAL TRANSMITTANCE,MIN. INSULATION  ";MIN;"BTU/HR-FT2-F"
310  PRINT "THERMAL TRANSMITTANCE,MED. INSULATION";MED;"BTU/HR-FT2-F"
320  PRINT "THERMAL TRANSMITTANCE,MAX. INSULATION";MAX;"BTU/HR-FT2-F"
330  'Next define variables that will change only under program development
340  TF = 31   'Final temperature of slush ice mixture, Fahrenheit
350  D  = 42   'Maximum allowed fish loading density, Lbm/Ft3
360  VOLBKLICE = 67  'This is the volume (Cubic feet per ton) of dry bulk flake ice
370  PRINT
380  PRINT "CSW TEMPERATURE                              ";TF;"F"
390  PRINT "MAXIMUM PERMITTED FISH PACKING DENSITY";D;"LBM/FT3"
400  PRINT "SPECIFIC VOL OF DRY BULK-LOADED ICE ";VOLBLKICE;"FT3/TON"
410  PRINT
420  PRINT
430  'Now define variables that may vary with each case
440  INPUT "TYPE IN OCEAN TEMPERATURE, IN DEGREES FAHRENHEIT";TI
450  PRINT
460  INPUT "TYPE IN HOLD OR TANK VOLUME, IN CUBIC FEET"; VTOT
470  PRINT
480  INPUT "TYPE IN THE NUMBER OF DAYS ICE WILL BE IN THE TANK";TIME
490  PRINT
491  INPUT "TYPE IN THE NUMBER OF HOURS PER DAY BUBBLED AIR IS TO
     CIRCULATE";TAIR
492  PRINT
500  PRINT "IF CASE 1 IS FOR FILL/SPILL"
510  PRINT "    CASE 2 IS FOR FILL/NO-SPILL"
520  PRINT "    CASE 3 IS FOR NO-FILL/NO-SPILL"
530  PRINT
531  INPUT "TYPE IN THE CASE NUMBER TO BE CALCULATED";CASE
538  LPRINT
539  LPRINT
540  LPRINT
541  LPRINT "CASE";CASE;
542  IF CASE=1 THEN LPRINT "FILL/SPILL"
543  IF CASE=2 THEN LPRINT "FILL/NO-SPILL"
544  IF CASE=3 THEN LPRINT "NO-FILL/NO-SPILL"
545  LPRINT
550  PRINT
560  PRINT "IF 'MIN' DESCRIBES A TANK HAVING ESSENTIALLY NO INSULATION"
580  PRINT "    'MED' DESCRIBES A MARGINALLY INSULATED TANK,"
590  PRINT "    'MAX' DESCRIBES A WELL-INSULATED TANK,"
600  PRINT
610  INPUT "TYPE INSULATION DESCRIPTION AS MIN, MED, OR MAX";U$
620  IF U$ = "MIN"   THEN U = MIN
621  IF U$ = "min"   THEN U = MIN
630  IF U$ = "MED"   THEN U = MED
631  IF U$ = "med"   THEN U = MED
640  IF U$ = "MAX"   THEN U = MAX
641  IF U$ = "max"   THEN U = MAX
650  PRINT
660  INPUT "TYPE IN THE TONS OF FISH TO BE ADDED TO THIS CSW TANK"; MF
670  IF MF*2000/VTOT <= D GOTO 740
680  PRINT "                    *****"
690  PRINT "WARNING: FISH LOADING DENSITY EXCEEDS MAXIMUM ALLOWED
     VALUE OF";
700  PRINT D; "LBM/FT3"
710  PRINT "TRY LOADING LESS FISH"
720  PRINT "                    *****"
730  GOTO 660
740  PRINT
750  PRINT
760  MIFISH  = MF*CF*(TI-TF)/LI 'Total ice melt for fish
770  MILKDA = .0864*U*VTOT↑.6678*(TI-TF)/LI 'Ice melt per day for heat leak
780  MILEAK = MILKDA*TIME
781  MIAIR   = .08*((VTOT/6200)↑.667)*TAIR*TIME 'Ice melt per trip due to air
790  ON CASE GOSUB 1110, 1370, 1700
860  L PRINT "INITIAL TEMPERATURE                        ";TI;"F"
870  LPRINT "TANK VOLUME                                ";VTOT;"CUBIC FEET"
880  LPRINT "FISH TO BE LOADED                          ";
881  LPRINT USING   "###.#";MF;
882  LPRINT "  TONS"
890  LPRINT "NUMBER OF DAYS TO BE HELD                  ";TIME;"DAYS"
891  LPRINT "HOURS PER DAY OF AIR BUBBLING              ";TAIR;"HOURS"
900  LPRINT "ASSUMED INSULATION LEVEL                   ";
910  IF U=MIN THEN LPRINT "MIN"
920  IF U=MED THEN LPRINT "MED"
930  IF U=MAX THEN LPRINT "MAX"
```

(Continued on next page.)

Appendix Table 2. continued.

```
940  LPRINT "ICE MELT FROM FISH                    ";
950  LPRINT USING "##.#";MIFISH;
960  LPRINT "  TONS"
1000 LPRINT "ICE MELT FROM HEAT LEAK               ";
1010 LPRINT USING "##.#  "; MILEAK;
1020 LPRINT "  TONS"
1021 LPRINT "ICE MELT FROM BUBBLED AIR             ";
1022 LPRINT USING "##.#";  MIAIR;
1023 LPRINT "  TONS"
1030 ON CASE GOSUB 1300, 1630, 1950
1040 VOLICE = VOLBLKICE*MI*100/VTOT
1050 LPRINT "APPROX PERCENTAGE OF TANK  "
1060 LPRINT "  OCCUPIED BY DRY  "
1070 LPRINT "  BULK-LOADED ICE                     ";
1080 LPRINT USING "###"; VOLICE
1081 CLS
1082 PRINT "*****************************************************"
1083 PRINT
1084 PRINT " IF YOU'RE FINISHED RUNNING CASES,"
1085 PRINT"TYPE 'CANCEL' (WANG) OR 'CONTROL - BREAK' (IBM)"
1086 PRINT
1087 PRINT "*****************************************************"
1088 PRINT
1089 PRINT
1090 GOTO 440
1091 STOP
1092 END
1100 END
1110 'Case 1 is for continually flooded tank; cold water spilled as fish added
1120 MIWATVOL = (RHOI/2000 - (MILEAK + MIAIR + MIFISH)/VTOT) / (1 +
     (RHOI*LI)/(RHOW*CW*(TI -TF)))  'Mass of ice per unit volume to chill water
1130 MIWAT = MIWATVOL*VTOT
1140 MI = MIFISH + MILEAK + MIAIR +MIWAT
1150 IF VOLBLKICE*MI <= VTOT GOTO 1210
1160 PRINT "     *****"
1170 PRINT "  WARNING: INITIAL BULK ICE VOLUME EXCEEDS TANK VOLUME BY  ";
1171 PRINT USING "###."; (VOLBLKICE*MI-VTOT)/VTOT*100;
1172 PRINT "  %"
1180 PRINT "  TRY BETTER INSULATION OR LESS FISH."
1190 PRINT "     *****"
1200 GOTO 560
1210 IF VOLBLKICE*MI <= .9*VTOT GOTO 860
1220 LPRINT "     *****"
1230 LPRINT "WARNING: INITIAL BULK ICE VOLUME EXCEEDS 90% OF TANK
     VOLUME."
1240 LPRINT "  MAY HAVE DIFFICULTY LOADING INITIAL CATCH."
1250 LPRINT "     *****"
1260 GOTO 860
1300 LPRINT "ICE MELT FROM WATER ADDED             ";
1310 LPRINT USING "##.#"; MIWAT;
1320 LPRINT "TONS"
1330 LPRINT "TOTAL ICE REQUIRED                    ";
1340 LPRINT USING "##.#";MI;
1350 LPRINT "  TONS"
1360 RETURN
1370 'Case 2 is for an ultimately flooded tank; no water is spilled
1380 'as fish is added
1384 VOLPRIME = (VOLBLKICE*(MILEAK+MIAIR+MIFISH)*LI)/(LI+(RHOW/RHOI)*CW*
     (TI-TF)-(VOLBLKICE/2000)*RHOW*CW*(TI-TF))
1385 MIWAT  =  ((RHOW*CW*RHOI*(TI-TF)/2000)/(RHOI*LI+RHOW*CW*(TI-TF)))*
     (VOLPRIME-(MILEAK+MIAIR+MIFISH)*2000/RHOI)
1386 IF VOLPRIME < VTOT GOTO 1394
1387 PRINT "                         *****"
1388 PRINT "WARNING: ICE/WATER MIXTURE EXCEEDS TANK VOLUME. NO ROOM
     FOR FISH."
1389 PRINT "                         TRY BETTER INSULATION OR LESS FISH"
1390 PRINT "                         *****"
1391 GOTO 560
1394 N=0
1395 VOLWAT = MIWAT*LI*2000/(RHOW*CW*(TI-TF))
1400 IF (VOLPRIME + MF*2000/RHOF) < VTOT GOTO 1440
1405 IF (VOLPRIME + MF*2000/RHOF) = VTOT GOTO 1470
1410 IF N< 0 GOTO 1470
1415 MF = .99*MF
1420 MIFISH = MF*CF*(TI-TF)/LI
1425 VOLPRIME = (VOLBLKICE*(MILEAK+MIAIR+MIFISH)*LI)/(LI+(RHOW/RHOI)*CW*
     (TI-TF)-(VOLBLKICE/2000)*RHOW*CW*(TI-TF))
1426 MIWAT  =  ((RHOW*CW*RHOI*(TI-TF)/2000)/(RHOI*LI+RHOW*CW*(TI-TF)))*
     (VOLPRIME-(MILEAK+MIAIR+MIFISH)*2000/RHOI)
1430 N = 1
1435 GOTO 1400
1440 IF N > 0 GOTO 1470
1445 VOLWAT = 1.01*VOLWAT
1450 MIWAT = VOLWAT*RHOW*CW*(TI-TF)/(LI*2000)
1455 VOLPRIME = (MIWAT + MILEAK + MIAIR + MIFISH) *2000/RHOI + VOLWAT
1460 N = -1
1465 GOTO 1400
1470 MI = MIFISH + MILEAK + MIAIR + MIWAT
1472 IF N<1 GOTO 1500
1475 LPRINT "     *****"
1480 LPRINT "TANK CAPACITY IS INADEQUATE TO HOLD ALL THE FISH REQUIRED."
1485 LPRINT "THE PROGRAM HAS DECREASED THE INPUT AMOUNT OF FISH TO
     BE LOADED."
1490 LPRINT "     *****"
1495 GOTO 860
1500 LPRINT "     *****"
1505 LPRINT "EXTRA WATER HAS BEEN ADDED TO FILL THE TANK"
1510 LPRINT "     *****"
1515 GOTO 860
1630 LPRINT "ICE MELT FROM WATER ADDED             ";
1640 LPRINT USING "##.#"; MIWAT;
1650 LPRINT "  TONS"
1660 LPRINT "TOTAL ICE REQUIRED                    ";
1670 LPRINT USING "##.#"; MI;
1680 LPRINT "  TONS"
1690 RETURN
1700 'Case 3 is for a partially flooded tank
1710 VOLPRIME = (VOLBLKICE*(MILEAK+MIAIR+MIFISH)*LI)/(LI+(RHOW/RHOI)*CW*
     (TI-TF)-(VOLBLKICE/2000)*RHOW*CW*(TI-TF))
1711 MIWAT  =  ((RHOW*CW*RHOI*(TI-TF)/2000)/(RHOI*LI+RHOW*CW*(TI-TF)))*
     (VOLPRIME-(MILEAK+MIAIR+MIFISH)*2000/RHOI)
1720 IF VOLPRIME < VTOT GOTO 1780
1730 PRINT "     *****"
1740 PRINT "WARNING: ICE/WATER MIXTURE EXCEEDS TANK VOLUME. NO ROOM
     FOR FISH."
1750 PRINT "TRY BETTER INSULATION OR LESS FISH"
1760 PRINT "     *****"
1770 GOTO 560
1780 VOL = VOLPRIME +MF*2000/RHOF
1790 IF VOL <= VTOT GOTO 1850
1800 PRINT "     *****"
1810 PRINT "WARNING: VOLUME OF FISH AND CSW EXCEEDS TANK VOLUME."
1820 PRINT "TRY PACKING LESS FISH"
1830 PRINT "     *****"
1840 GOTO 660
1850 VOLWAT = MIWAT*LI*2000/(RHOW*CW*(TI-TF))
1851 N=0
1852 IF MF*2000/VOL <= D GOTO 1930
1855 VOLWAT = 1.01*VOLWAT
1860 MIWAT = VOLWAT*RHOW*CW*(TI-TF)/(LI*2000)
1865 VOLPRIME = (MIWAT + MIAIR + MILEAK +MIFISH)*2000/RHOI + VOLWAT
1870 VOL = VOLPRIME + MF*2000/RHOF
1875 N = 1
1880 GOTO 1852
1930 MI = MIWAT + MILEAK + MIAIR + MIFISH
1931 IF N < 1 GOTO 1940
1932 LPRINT "     *****"
1933 LPRINT "PROGRAM HAS ADDED EXTRA WATER AND ICE TO REDUCE FISH
     PACKING DENSITY"
1934 LPRINT "  TO AN ACCEPTABLE VALUE"
1935 LPRINT "     *****"
1940 GOTO 860
1950 LPRINT "ICE MELT FROM WATER ADDED             ";
1960 LPRINT USING "##.#"; MIWAT;
1970 LPRINT "  TONS"
1980 LPRINT "TOTAL ICE REQUIRED                    ";
1990 LPRINT USING "##.#";MI;
2000 LPRINT "  TONS"
2010 LPRINT "FISH LOADING DENSITY                  ";
2020 LPRINT USING "##.#";MF*2000/VOL;
2030 LPRINT "  POUNDS PER CUBIC FOOT"
2040 LPRINT "PERCENTAGE OF VOLUME OCCUPIED"
2050 LPRINT "BY ICE/WATER/FISH MIXTURE             ";
2060 LPRINT USING "##.#"; VOL*100/VTOT
2070 RETURN
```

Parameters Affecting Viscosity as a Quality Control for Frozen Fish

A. J. BORDERÍAS, F. JIMÉNEZ-COLMENERO, and M. TEJADA

Introduction

Several authors have reported decreases in the viscosity of proteins from frozen fish isolated in high ionic strength solutions, and this has been attributed to protein aggregation, with a subsequent reduction in the number of bonds between the proteins and the medium (Matsumoto, 1980).

Work carried out at the authors' Institute (Jiménez-Colmenero and Borderías, 1983; Tejada et al.[1]) has shown a correlation between the viscosity value and both protein solubility and emulsifying capacity in frozen muscle. It has also been found, and this is especially true for white fish (i.e., blue whiting, cod, hake), that the values obtained using this technique in tests of frozen muscle during the storage period are highly significant, such that the sets of measurement readings provide a clear picture of the quality of the frozen product. Other authors (Groninger et al., 1983) have employed a similar method of measuring the functional properties of proteins.

Therefore, this technique would seem to be appropriate for use as an index of the quality of frozen fish protein. Moreover, the speed and ease of the method, and the fact that it can be performed using relatively unsophisticated equipment, make it ideal for use both in the laboratory and in industrial situations. Our study examined the influence of various parameters affecting apparent viscosity on this quality control method.

[1]Tejada, M., A. J. Borderías, and F. Jiménez-Colmenero. 1984. Contribución de las proteínas miofibrilares y sarcoplásmicas a las modificaciones de ciertas propiedades funcionales del músculo durante su conservación al estado congelado. Paper presented at the International Symposium on Alterations in the Chemical Constituents of Foods in Industrial Processing. Valencia, Spain, 5-7 Nov.

ABSTRACT—The measurement of apparent viscosity may be an appropriate method of quality control for myosystems undergoing frozen storage. Our experiment studied parameters affecting the measurement of apparent viscosity of homogenated muscle of Atlantic cod, Gadus morhua, *in 5 percent NaCl solution as a quality control method for frozen fish.*

Parameters like the ratio of muscle to saline solution, pH, homogenation time and method, time elapsing between homogenation and viscosity measurement, and temperature were studied to establish and standardize the optimum conditions for measurement. On the basis of the results obtained, these conditions were: Ratio of muscle to 5 percent NaCl solution, 1:4; homogenation for 1 minute; a pH of between 6.5 and 7; a time between homogenation and viscosity measurement of 30-60 minutes; and a blending/viscosity measurement temperature of between 2° and 5°C.

Materials and Methods

Atlantic cod, *Gadus morhua*, caught 5-7 days earlier and preserved chilled, was purchased at a local market. The muscle was minced using a mincer with plate orfices 5 mm in diameter. The mince was divided into 300 g lots which were packaged on trays wrapped in aluminium foil. The samples were frozen in a tunnel freezer at −30°C with an air flow of 5 m/second and then vacuum-packed and stored at −24°C for the 5 days during which tests were made.

The apparent viscosity (η_{app}) was measured using a Brookfield[2] model RVT rotary viscometer with flat spindles numbers 2, 3, and 4 at a speed of 20 rpm. Measurements were taken after 3 minutes of spindle operation, and at least four replicates were performed.

[2]Mention of trade names or commercial firms does not imply endorsement by the National Marine Fisheries Service, NOAA.

The basic steps of this procedure are diagrammed in Figure 1, and the standard conditions applied in the procedure are set out below:

1) Ratio g of muscle:ml 5 percent NaCl solution: 1:4.
2) pH: 6.5-7.0.
3) blender, speed setting, and time: Omni-mixer, setting 7, 1 minute.
4) homogenate temperature: 3-5°C.
5) standing time: 30 minutes.

In addition to the standard conditions, the following variations were also tested:

1) Ratio g of muscle:ml 5 percent NaCl solution: 1:4, 1:6, 1:8, and 1:10, corresponding to 20.0, 14.3, 11.1, and 9.1 g of fish/100 ml of homogenate.
2) pH: 4.85, 5.53, 6.57, 6.61, 6.70, 6.93, 7.60, 8.33, and 9.10.
3) Blender and blending time: Omnimixer (1, 2, and 3 minutes) and Ultraturrax (1 minute at middle speed setting).
4) Blending/viscosity measurement temperature (°C): 2.2, 3.6, 4.8, 10.0, 14.5, 14.9, 15.3, 17.5, 21.3, and 25.0.
5) Standing time (minutes): 0, 30, 70, 100, 165, 240, and 300.
6) Homogenate centrifuging conditions: 3 minutes at 3,000 rpm at 3°C.

Regression curves were calculated by computer; the significance levels of the

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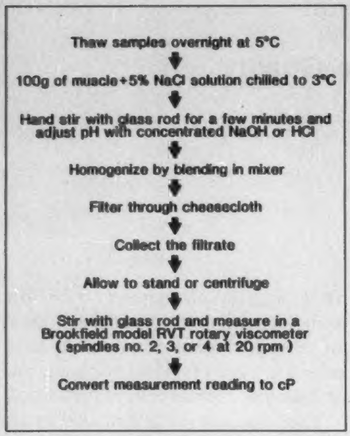


Figure 1.—Method of measuring the apparent viscosity.

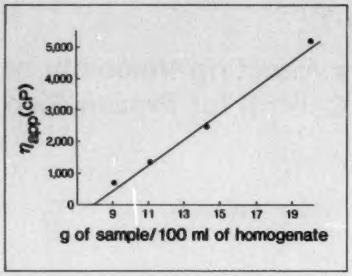


Figure 2.—Changes in apparent viscosity with sample concentration.

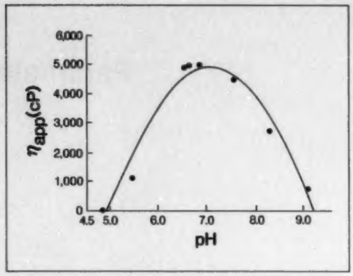


Figure 3.—Apparent viscosity vs. pH.

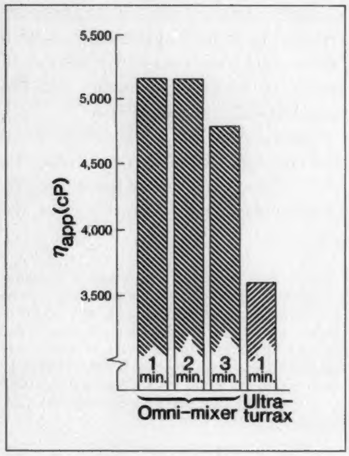


Figure 4.—Apparent viscosity vs. blender, speed setting, and blending time.

curves were calculated using an F test and the goodness of fit with the index of determination (r^2).

Results and Discussion

Ratio Samples: 5 Percent NaCl Solution

Figure 2 shows that there is a linear relationship ($r^2 = 0.95$; $P < 0.01$) between homogenated sample concentration and apparent viscosity, as was found for other species (Borderías et al., 1985). In accordance with this relationship, at less than 8 g of muscle/100 ml of homogenate, apparent viscosity did not register on the measurement scale under the experimental conditions employed. At levels above 20 g/100 ml, the homogenate was too viscous, making measurement difficult. The ratio of one part sample to four parts 5 percent NaCl solution was the most appropriate for measuring viscosity for quality control purposes, since a high initial apparent viscosity is needed, because it tends to decrease with storage time, and may even drop to zero in whitefish such as cod after 3 months at −12°C (Tejada et at.[1]).

Effect of pH

The relationship between the pH and apparent viscosity was given by a third-degree polynomial ($r^2 = 0.94$; $P < 0.01$) plotted in Figure 3. Figure 3 shows that the highest viscosity values corresponded to a pH of between 6.5 and 7; minimum values were recorded at pH 4.8 and 9.1. On the basis of these data the behavior of cod muscle would appear to differ from that of red meat, since Hamm (1975) recorded minimum viscosity values at about pH 5.3 (isoelectric point), with values increasing as one moved away from that point. This seems reasonable since the isoelectric point of proteins drops in the presence of NaCl (Schut, 1976). The decrease in viscosity at alkaline pH levels might be due to aggregation, which, in the conditions employed, was not reversible when the medium was neutralized on reaching pH 9.

Consequently, because of the fluctuations in viscosity with pH, it is imperative to adjust the mixture's pH level before any measurement readings are taken. It is further advisable to adjust the pH prior to blending, since differences in viscosity were observed when the pH was adjusted before and after homogenation. The recommended pH is between 6.5 and 7, corresponding to the point at which the highest viscosity values were recorded.

Effect of Blender, Speed Setting, and Blending Time

The greater destruction of tissues during homogenation led to a decrease in apparent viscosity (Fig. 4). Maximum viscosity in the shortest time was obtained by blending in an Omni-mixer for 1 minute.

Standing Time

It is advisable to allow some standing time between homogenation and the viscosity measurement to permit the release of air bubbles formed during blending, since these may result in measurement variations, and also to permit the formation of bonds between the proteins and the solvent.

To study this effect, various standing times were employed between homogenation and viscosity measurement.

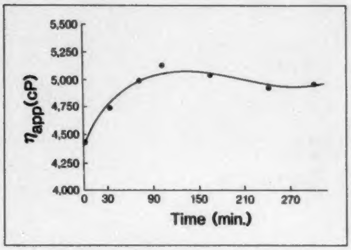


Figure 5.—Apparent viscosity vs. the time elapsing from blending to measurement.

Figure 5 shows that the relationship between the viscosity of the homogenate and the time elapsing between blending and measurement was given by a third-degree polynomial (r^2 = 0.95; P < 0.05). Figure 5 also indicates that the measurement readings stabilized after a standing time of 60 minutes or more at 3-5°C.

Effect of Centrifuging

Centrifuging the homogenates prepared as described in the section on materials and methods was also used to eliminate the air bubbles, employing the method described by Hermansson (1975). However, centrifuging makes the quality control method more complicated, and the authors found no advantage in its use.

Blending/Measurement Temperature

Figure 6 shows that the relationship between apparent viscosity and temperature was given by a second-degree polynomial (r^2 = 0.84; P < 0.01). The curve indicates that fluctuations in viscosity are lowest and viscosity values are highest at between 0° and 7°C, hence it is advisable to make readings at a temperature of from 2° to 5°C. At higher temperatures, alterations in the properties of the proteins are more likely.

Summary

From the foregoing it would appear that the optimum condition for applying this technique of apparent viscosity measurement as a quality control method are as follows:

1) Grams of muscle:ml 5 percent NaCl solution: 1:4.
2) Blending time: 1 minute.
3) Blender: Omni-mixer.
4) Blending/measuring temperatures: 2-5°C.
5) pH: 6.5-7.0.
6) Standing time in refrigerator between blending and measurement reading: 60 minutes.

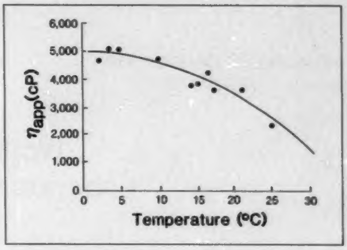


Figure 6.—Apparent viscosity vs. temperature.

Literature Cited

Borderías, A. J., F. Jiménez-Colmenero, and M. Tejada. 1985. Viscosity and emulsifying ability of fish and chicken muscle protein. J. Food Technol. 20:31-42.

Groninger, H., J. W. Hawkes, and J. K. Babbitt. 1983. Functional and morphological changes in processed frozen fish muscle. J. Food Sci. 48:1388-1390.

Hamm, R. 1975. On the rheology of minced meat. J. Texture Studies 6:281.

Hermansson, A. M. 1975. Functional properties of proteins for foods - flow properties. J. Texture Studies 5:425-439.

Jiménez-Colmenero, F., and A. J. Borderías. 1983. A study of the effects of frozen storage on certain functional properties of meat and fish protein. J. Food Technol. 18:731-737.

Matsumoto, J. J. 1980. Chemical deterioration of muscle proteins during frozen storage. *In* J. R. Whitaker and M. Fujimaki (editors), Chemical deterioration of proteins, p. 95-124. ACS Symp. Ser. 123. Am. Chem. Soc., Wash., D.C.

Schut, J. 1976. Meat emulsions. *In* S. Friberg (editor), Food Emulsions, p. 385-458. Marcel Dekker, Inc., N.Y. 385-458.

World's Oldest Fisheries Research Laboratory Celebrates Centennial of Service

The world's oldest fisheries research laboratory, NOAA's Woods Hole Laboratory in Massachusetts, celebrated its centennial 13-16 August 1985. Five public lectures, two technical forums, a historical exhibit, and a rededication ceremony highlighted the celebration.

Lectures

The lectures, free to the public, dealt with the history and future of marine ecology, fisheries research and management, and the Woods Hole scientific institutions. John Steele, Director of the nearby Woods Hole Oceanographic Institution, opened the lecture series on 13 August at Lilly Auditorium with his presentation on "Advances in Marine Ecology and Relevance to Fisheries." Later that evening, Robert L. Edwards spoke on "History and Contributions of the Woods Hole Fisheries Laboratory." Edwards was formerly Director of the Northeast Fisheries Center, the coordinating organization for the Woods Hole Laboratory and six other National Marine Fisheries Service laboratories in the New England and Mid-Atlantic states. He is currently Technical Assistant to the NOAA Assistant Administrator for Fisheries.

At 10:00 a.m. on 14 August at Redfield Auditorium, Paul R. Gross, President and Director of the Marine Biological Laboratory (MBL) in Woods Hole, spoke on "The MBL and the Fisheries: A Century of Cooperation in Woods Hole," and at 2:00 p.m. at the Lilly Auditorium, William F. Royce lectured on "100 Years of Development in Fisheries Science and Management." Royce was formerly the Director of the Woods Hole Laboratory, and is currently an international fisheries consultant in Seattle, Wash. Peter A. Larkin, Professor at the University of British Columbia, closed the lecture series at 7:30 p.m. at Redfield Auditorium with a look at "Fisheries Research Strategy for the Future."

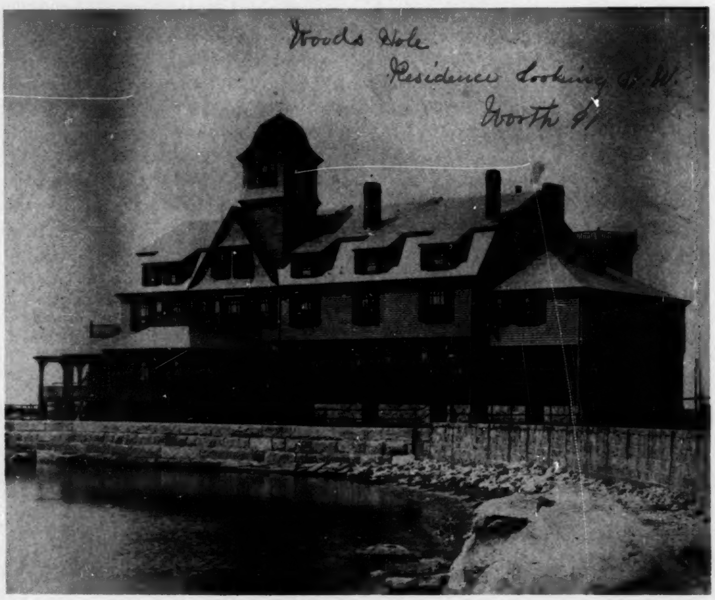
Technical Sessions

Two forums on 15 August discussed the future of North American fisheries research and management. The morning forum dealt with "Fisheries Research Strategy for the Future." Participants scheduled were Carl R. Sullivan, Moderator (Executive Director, American Fisheries Society); Peter A. Larkin; John L. McHugh (Professor, State University of New York); Gilbert C. Radonski (President, Sport Fishing Institute); and William F. Royce. The afternoon forum dealt with "Fisheries Management in the 1980's and Beyond." Participants were to be Richard H. Schaefer, Moderator (Northeast Regional Director, National Marine Fisheries Service); William G. Gordon (NOAA Assistant Administrator for Fisheries); Alan D. Guimond (Chairman, New England Fishery Management Council); Robert L. Martin (Chairman, Mid-Atlantic Fishery Management Council); Allen E. Peterson, Jr. (Director, NMFS Northeast Fisheries Center); Jeff Pike (Assistant to U.S. Representative Gerry E. Studds); Gilbert C. Radonski; and Lucy Sloan (Executive Director, National Federation of Fishermen).

Historical Exhibit

Beginning on 13 August, the fisheries lab's public display aquarium featured a special exhibit on the lab's history, as

The Woods Hole Laboratory, 1885.



well as new exhibits on current research. The historical exhibit included a chronological display of old photos, newspaper clippings, field notebooks, sampling gear, etc., from the fisheries lab's past. The lab's aquarium, also open, featured fish tanks, "hands-on" tanks, a seal pool, and educational displays; scientists were avilable to answer questions. The special exhibit closed with the aquarium's traditional 15 September switch from summer hours to winter hours.

Rededication

The rededication of the Woods Hole Laboratory took place on 16 August, with national, state, and local officials participating, including Anthony J. Calio, Acting NOAA Administrator, and William G. Gordon. Research in the Woods Hole Laboratory focuses on populations of commercially and recreationally important fishes in the U.S. Fishery Conservation Zone (3-200 miles offshore) from the Canadian border to Cape Hatteras, N.C., as well as on the habitats which produce those populations. Information from this research is used by the New England and Mid-Atlantic Fishery Management Councils to manage their regions' fisheries which are worth $1 billion annually to the nation's economy.

NMFS Outstanding Publications Cited

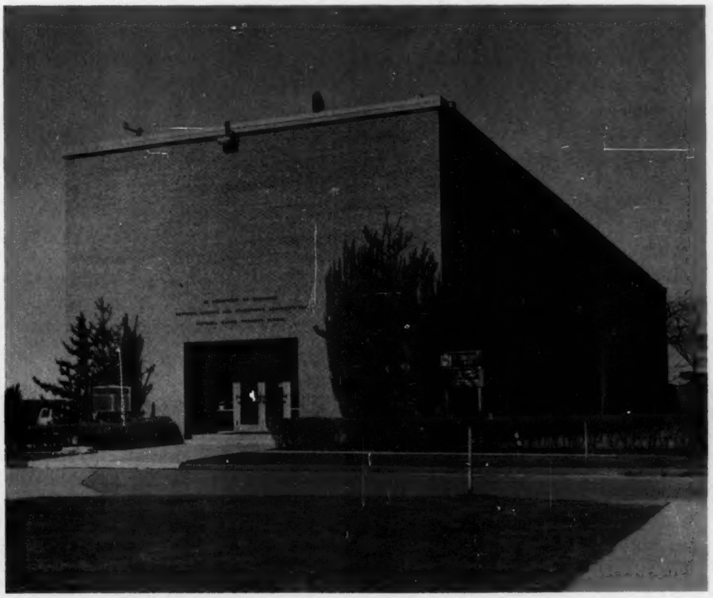
Winners of the National Marine Fisheries Service's Outstanding Publications Award for papers published in the *Marine Fisheries Review* (Vol. 45) and the *Fishery Bulletin* (Vol. 81) have been announced by NMFS Publications Advisory Committee Chairman Ben Drucker.

"To Increase Oyster Production in the Northeastern United States," by Clyde L. MacKenzie, Jr., of the Northeast Fisheries Center's Sandy Hook Laboratory, Sandy Hook, N.J., was selected by the Awards Committee as the best paper in the *Marine Fisheries Review*, 45(3): 1-22. And, "Seasonal Variation in Survival of Larval Northern Anchovy, *Engraulis mordax*, Estimated From the Age Distribution of Juveniles" by R. D. Methot, Jr., of the NMFS Southwest Fisheries Center, La Jolla, Calif., was selected as the best paper in the *Fishery Bulletin*, 81(4):741-750.

In all, nine papers were nominated from the *Bulletin* and four from the *Review*. The other three *Marine Fisheries Review* papers nominated for excellence were "Fatty Acids and Lipid Classes of Three Underutilized Species and Changes Due to Canning" by M. B. Hale and T. Brown, 45(4-6):45-48; "Incidental Catch of Marine Mammals by Foreign Fishing Vessels" by T. R. Loughlin, L. Consiglieri, R. L. DeLong, and A. T. Actor, 45(7-8-9): 44-49; and "Some Effects of Mt. St. Helens Volcanic Ash on Juvenile Salmon Smolts" by T. W. Newcomb and T. A. Flagg, 45(2):8-12.

The eight other *Fishery Bulletin* papers nominated for excellence were "Copepods and Scombrid Fishes: A Study in Host-Parasite Relationships" by R. F. Cressey, B. B. Collette, and J. L. Russo, 81(2):227-265; "Yield per Recruit Models of Some Reef Fishes of the U.S. South Atlantic Bight" by G. R. Huntsman, C. S. Manooch III, and C. B. Grimes, 81(4):679-695; "Interrelationships Between Juvenile Salmonids and Nonsalmonid Fish in the Columbia River Estuary" by G. T. McCabe, Jr., W. D. Muir, R. L. Emmett, and J. T. Durkin, 81(4):815-826; "Analyzing the Width of Daily Otolith Increments to Age the Hawaiian Snapper, *Pristipomoides filamentosus*" by S. Ralton and G. T. Miyamoto, 81(3):523-535; "Population Assessment of the Gray Whale, *Eschrichtius robustus*, From California Shore Censuses" by S. B. Reilly, D. W. Rice, and A. A. Wolman, 81(2):267-282; "Changes in Size of Three Dolphin (*Stenella* spp.) Populations in the Eastern Tropical Pacific" by T. D. Smith, 81(1):1-13; "Movement of Sablefish, *Anoplopoma fimbria*, in the Northeastern Pacific Ocean as Determined by Tagging Experiments (1971-80)" by V. G. Wespestad, K. Thorsen, and S. A. Mizroch, 81(2):415-420; and "The Mud Crab, *Panopeus herbstii*, s.l. Partition Into Six Species (Decapoda: Xanthidae)" by A. B. Williams, 81(4):863-882.

The Woods Hole Laboratory, 1985.



Developed in 1975, the annual outstanding publication awards program recognizes NMFS employees who have made exceptional contributions to the knowledge and understanding of the resources, processes, and organisms studied as a part of the NMFS mission. Authors must have been employed by the NMFS at the time the paper was published. *Marine Fisheries Review* papers must be effective and interpretative contributions to the understanding and knowledge of NMFS mission-related studies, while *Fishery Bulletin* papers must document outstanding scientific work.

At the close of each volume, nominations are solicited from the NMFS Center, Regional, and Office Directors for the awards by the Awards Committee Chairman—the editor of the *Fishery Bulletin*, currently William J. Richards. Other Committee members include the editor of the *Marine Fisheries Review*, W. L. Hobart, and the former *Fishery Bulletin* editors Reuben Lasker, Bruce Collette, and Carl Sindermann.

NODC Taxonomic Code Doubles in Size

NOAA's National Oceanographic Data Center (NODC) has announced the availability of the fourth edition of the "NODC Taxonomic Code." This edition contains nearly 46,000 entries giving the scientific names and corresponding numerical codes of worldwide flora and fauna from viruses to mammals, nearly twice the number included in the third edition.

The "NODC Taxonomic Code" is a hierarchical system of numerical codes of up to 12 digits used to represent the scientific names of organisms to the level of subspecies or variety. The bowhead whale, *Balaena mysticetus*, for example, is coded by the 10-digit number 9219030102. The code links the Linnean system of biological nomenclature to a numerical schema that facilitates modern methods of data storage and retrieval. The code was specifically developed by NODC to simplify and systematize NODC processing, storage, and retrieval of marine biological data. NODC requires the use of the code in all marine biological data that it accepts for processing.

To help overcome recognized shortcomings of the code rooted in the rigidity of the numerical schema, this edition introduces new features to make the code more flexible and useful. For example, a series of terms and symbols is now used to annotate code entries with information about changes or corrections and to provide cross-references between certain related entries.

The published version of the code (Key to Oceanographic Records Documentation No. 15) is available either as a paper copy or on microfiche. The "NODC Taxonomic Code" is also available on magnetic tape.

Code Structure

The NODC codes contain a maximum of 12 digits. Each two digits represent one or more levels of the taxonomic hierarchy as follows (numbers in this example are fictitious:

93	(2 digits)	Subkingdom, Phylum, Subphylum, Class, Superorder, Order
9301	(4 digits)	Superclass, Class, Subclass, Superorder, Order, Suborder, Infraorder, Section, Superfamily
930101	(6 digits)	Class, Order, Suborder, Family, Subfamily[1]
93010101	(8 digits)	Genus
9301010101	(10 digits)	Species
930101010101	(12 digits)	Subspecies, Variety

Actual presentations vary in complexity from group to group and may exclude certain levels of taxonomy. The following is an example of a relatively simple code sequence (note that in this particular example there are no orders):

90	Reptilia	Class
9001	Reptilia Anapsida	Subclass
900205	Dermochelidae	Family
90020501	*Dermochelys*	Genus
9002050101	*Dermochelys coriacea*	Species
900205010101	*Dermochelys coriacea coriacea*	Subspecies

[1]A few subfamilies were used in the basic code framework; otherwise subfamilies are not recognized and additional subfamilies cannot be added to the code.

The following is a more complex example involving a larger number of recognized taxonomic levels (the final subspecies is fictitious):

34	Protozoa	Phylum
3438	Sarcodina	Superclass
3439	Rhizopodea	Class
3446	Rhizopodea Granuloreticulosa	Subclass
3448	Rhizopodea Granuloreticulosa Foraminifera	Order
3450	Rhizopodea Granuloreticulosa Formanifera Textularina	Suborder
345001	Ammodiscacea	Superfamily
345002	Ammodiscacea Astrorhizidae	Family
345005	Ammodiscacea Astrorhizidae Hippocrepininae	Subfamily
34500501	*Hippocrepina*	Genus
3450050101	*Hippocrepina indivisa*	Species
345005010101	*Hippocrepina indivisa indivisa*	Subspecies

In the third edition common names and synonyms were printed in separate alphabetical listings and did not appear in the numerical listing. In the fourth edition all names (common and Linnean) and all previous numbers related to a given taxon are printed together in the numerical code listing.

Availability

The "NODC Taxonomic Code" is available on magnetic tape, on microfiche, and as a printed paper version. All three formats include the complete code in two separate sequences: 1) Numerical (code) order and 2) alphabetical (scientific name) order. On magnetic tape the two sort orders appear as separate files on one tape. For ease of use the microfiche and printed versions of the code appear in two volumes. Volume 1 contains the Numerical (Code Order) Listing and Volume 2 contains the Alphabetical (Scientific Name Order) Listing.

The prices at initial printing (subject to change without notice) of the three formats are as follows: 1) Magnetic tape (9-track, 1600 bpi, ASCII character code) = $90.00; 2) microfiche (5 fiche, 48× reduction) = $7.00; and 3) paper copy (738 pages in two volumes; 8½ × 11-inch pages) = $50.00.

Orders should be directed to: Nation-

al Oceanographic Data Center, User Services Branch, NOAA/NESDIS E/OC21, Washington, DC 20235. Telephone: 202-634-7500 (commercial) or FTS 634-7500. Payment may be made by check, money order, or credit card (Visa or MasterCard only). Checks and money orders should be made payable to "Department of Commerce/NOAA/NODC"; payments must be made in U.S. dollars and drawn on a bank located in the United States.

Calio Sworn in as New NOAA Administrator

Anthony J. Calio was sworn in as Administrator of the Commerce Department's National Oceanic and Atmospheric Administration (NOAA) on 7 October 1985, following his nomination by President Ronald Reagan and confirmation by the U.S. Senate. He had been NOAA's Deputy Administrator since December 1981. As Administrator, Calio establishes Federal policies and directs agency programs to improve the understanding, management, conservation, and development of America's marine and atmospheric resources.

Under Calio's direction, NOAA is responsible for investigating and understanding the chemical and physical state of our oceans and atmosphere; predicting weather and issuing severe storm warnings and forecasts to protect life and property; promoting the wise development and conservation of our living marine, coastal, and deep seabed mineral resources; and preserving endangered marine species, marine animals, and unique estuarine areas for the future. In addition, Calio advises and represents the Secretary of Commerce on issues involving the environment, fisheries, space, and high technology, and serves on the National Security Council Interagency Group on Space.

Before joining NOAA, Calio spent 18 years with the National Aeronautics and Space Administration (NASA) where, as Associate Administrator for Space and Terrestrial Applications, he managed the U.S. civil remote sensing and space communications programs. He also had management responsibility for the Viking and Voyager missions, and during 8 years at the Johnson Space Center he directed all scientific aspects of the Apollo Lunar and Skylab programs.

Prior to joining NASA in 1963, Calio was employed 10 years in private industry with the Mount Vernon Research Company, the American Machine and Foundry Company, and the Westinghouse Atomic Power Division where he was involved in pioneering work on the peaceful use of nuclear energy.

Calio is a fellow of the American Institute of Aeronautics and Astronautics and the American Astronautical Society, as well as a member of the American Geophysical Union. He has received numerous honors, including a Sloan Fellowship from the Stanford Graduate School of Business and NASA's Distinguished Service Medal (twice), the Exceptional Scientific Achievement Medal, the Exceptional Service Medal, and the Presidential Rank of Distinguished Executive.

Born in Philadelphia, Pa., in October 1929, Calio was graduated from the University of Pennsylvania with a B.A. degree in physics in 1953. He attended graduate school at the University of Pennsylvania and Carnegie Institute of Technology, and received a D.Sc (Hon.) degree from Washington University of St. Louis in 1974. He and his wife Cheryll Madison Calio reside in Potomac, Md.

Larval Fish Distribution Eyed Near OTEC Unit

The NOAA ship *Townsend Cromwell* completed in September the first of four planned 10-day cruises in waters around Oahu, Hawaii, to determine the vertical distribution of larval fishes, reports Richard S. Shomura, Director of the NMFS Southwest Fisheries Center's Honolulu Laboratory. According to Shomura, the main objective of the cruise was to determine the possible impact of Ocean Thermal Energy Conversion (OTEC) facilities on marine fishes.

The first large-scale OTEC facility, planned for Kahe Point, would withdraw very large volumes of warm surface water and deep, cold water, and use the thermal difference in the warm and cold water to generate electricity. Small, planktonic larvae of fishes would be drawn in with the water and could potentially suffer high mortalities as they pass through the plant. Understanding the depth distribution of larvae in waters near Kaha Point would allow a better assessment of the possible effects of the proposed facility on fisheries and fish populations around Oahu.

George W. Boehlert, Chief Scientist on the cruise, supervised the use of a new kind of collection gear to determine the depth distribution of larval fishes. The gear, called the MOCNESS, for multiple opening-closing net and environmental sensing system, actually has nine nets controlled by computer from aboard ship. Scientists on deck can monitor the exact depth of the gear, its speed through the water, and the salinity and temperature of the water where the fish larvae are sampled. This greater sampling resolution will allow scientists to determine the environmental factors used by the larvae to determine their position in the water column.

Large midwater trawls were also fished off the *Cromwell* to determine the abundance of juvenile fishes in the region. The largest catch in these hauls was consistently a filefish, *Pervagor spilosoma*, the same fish which had been washing up on Oahu beaches in the previous 9 months. Over 500 fish were caught in a single haul of the trawl. The filefish occurred up to 8 miles offshore, as far from shore as the ship sampled with the large net. Visiting scientists participating on the cruise were Yoshirou Watanabe from the Tohoku Regional Fisheries Research Laboratory of Shiogama, Japan, and H. Geoffrey Moser from the Southwest Fisheries Center La Jolla Laboratory.

In an earlier cruise, the *Townsend Cromwell* returned to her home port in Honolulu on 25 July after a 42-day trip to collect biological and oceanographic data from waters over and surrounding the central North Pacific seamounts. A secondary mission, Shomura reports, was to help establish scientific field camps for the study of the endangered Hawaiian monk seal at Laysan Island, Lisianski Island, and Pearl and Hermes Reef in the Northwestern Hawaiian Islands.

Chief scientist Michael P. Seki reported that the vessel conducted operations at NW and SE Hancock Seamounts and at an unnamed seamount in the extreme northern region of the Hawaiian Ridge beyond Kure Atoll. Fishery resources on the seamounts were first discovered in 1967 when large concentrations of pelagic armorhead and smaller amounts of alfonsin were found by a Soviet trawler. This led to almost immediate commercial exploitation by Soviet trawlers; Japanese trawlers entered the fishery in 1969. In 1973 the Japanese also began fishing with vertical handlines and bottom longlines on the slopes of the seamounts since these areas were inaccessible to trawlers.

Despite declining catches in the 9 years, foreign fishing vessels continued to operate at the seamounts through 1984. In 1985, the NMFS closed the seamounts located inside the U.S. 200-mile Fishery Conservation Zone (in particular the Hancock Seamounts) to foreign groundfish fishing. This cruise represented the first visit to the seamounts since its closure.

Fishing operations conducted on the *Cromwell* mainly involved trawls, bottom longlines, and vertical longlines. Armorhead catches with the bottom longline appeared to be highest during daylight hours on the upper slope areas. This is in contrast to the bottom trawl fishery which is conducted primarily at night above the summit.

Scientists on the *Cromwell* also collected free-drifting and actively swimming small organisms over and away from the summit at SE Hancock using several different nets. Along with oceanographic data taken, the samples will be used to evaluate the high productivity induced by the presence of the seamount.

Pacific Sardine Begins Comeback off California

The Pacific sardine, *Sardinops sagax*, whose dramatic decline in the late 1940's sparked a multi-million dollar scientific investigation, is making a comeback, according to marine biologists Patricia Wolf of the California Department of Fish and Game (CDFG) and Paul E. Smith of the National Marine Fisheries Service's (NMFS) Southwest Fisheries Center, in La Jolla, Calif.

Averaging about 9 inches in length and 4 ounces in weight, colored bluish above and silvery below, and with variable numbers of black spots arranged in uneven rows along the sides, sardines were the glamour fish of the second and third decades of this century. Then it supported the most valuable fishery in the United States in terms of tons landed at an annual yield of about 600,000 tons.

A severe decline in sardine landings, first noted in the Pacific Northwest, began during the 1945-46 season and moved progressively southward. A low was reached when California's 1953-54 sardine season yielded only 4,500 tons. Sardines, a standard food item packed in the familiar oval cans in mustard or tomato sauce, disappeared from American food market shelves.

To begin to understand the causes of the sardine decline, fishery biologists and oceanographers from the CDFG, NMFS, and the Scripps Institution of Oceanography organized under the umbrella of the California Cooperative Oceanic Fisheries Investigations (CalCOFI) to begin the most intensive study of any marine fish in U.S. coastal waters. Although not all fishery biologists have agreed on the reasons for the precipitous decline in the sardine landings, most believe that the prolonged heavy fishing which occurred from 1928-29 through 1945-46, combined with unfavorable environmental changes, resulted in the spectacular failure of the sardine fishery in California.

Acting on the advice of fishery biologists who advocated a complete ban on sardine fishing to permit the sardine resource to recover from extremely low levels, California legislators voted to prohibit sardine fishing in 1974. A feature of this law also provided for a 1,000-ton annual fishery when the CDFG determined that the population of adult sardines had reached 20,000 tons.

Signs of an encouraging increase appeared as early as 1981 as sardines occurred in ever greater numbers in the incidental catch of mackerel and live bait fisheries, aerial spotter observations, annual CDFG sea surveys, and, increasingly, as larvae in plankton collections made during NMFS biological surveys.

Because the population level of the Pacific sardine is too low to be estimated reliably by existing techniques, Wolf and Smith designed a new survey system to estimate whether the adult sardine population is above or below 20,000 tons, the number which would signal the beginning of a commercial fishery. Their approach was based on the egg production method developed earlier by NMFS scientists at the Southwest Fisheries Center. As a first step, Wolf and Smith calculated the minimum geographic area which they estimated encompassed a spawning population of 20,000 tons of adult sardines. The location and extent of the survey area, and the time of year of the survey, were determined from the historical record of occurrences of sardine eggs and larvae found in the plankton samples during those times in past years when the sardine biomass levels were estimated to be near 20,000 tons.

In May 1985 Wolf and Smith employed their new method off southern California over the total survey area. They found 11 biological stations positive for sardine eggs in a total spawning area of 710 n.mi.^{2}, indicating a very high probability that there was at least a 20,000-ton spawning biomass of sardines off California. Survey results were presented to the CDFG which planned to open a 1,000-ton limited sardine fishery on 1 January 1986. According to California law, the sardines caught may be used either as human or animal food or for reduction to fish meal.

So now this small fish, once hunted at night during the dark of the moon along the Pacific Coast from southern Baja California and into the Gulf of California, appears to be making a modest comeback. With a bit of luck, fishery biologists believe that the distinctive luminescent fireballs produced as the dense sardine schools move through the surface layers of the sea will once again be a nighttime sight off the California coast.

U.S. Commercial Fishermen Land 6.4 Billion Pounds in 1984

U.S. fishermen landed 6.4 billion pounds of fish and shellfish in 1984, down slightly (941,000 pounds) from 1983 but close to the 1980 record of 6.5 billion pounds, according to the Commerce Department's National Oceanic and Atmospheric Administration (NOAA). The price paid for those fish at the dock, $2.4 billion, was $5 million less than in 1983.

NOAA's National Marine Fisheries Service (NMFS) said increased landings of clams, salmon, and shrimp helped offset declines in other major species, such as menhaden, tuna, flounder, and rockfish. Fishermen received an average of 37 cents a pound for their fish and shellfish, unchanged from 1983.

Several records were set in 1984. They included landings of 24 million pounds of Alaska pollock (previous high was 5.6 million pounds in 1979), 132.9 million pounds of clams (previous high was 121.8 million pounds in 1974), and 59.5 million pounds of scallops (previous high was 45.6 million pounds in 1981). Anchovies decreased for the second consecutive year, with landings of 17.8 million pounds (down 4.5 million pounds from last year). Squid landings of 33.2 million pounds were down 4.7 million pounds from last year.

U.S. Ups Percentage of FCZ Fish Catch in 1984

Foreign nations caught more fish within the U.S. 200-mile fishery conservation zone in 1984 than in 1983 but less than the average for the preceding 5 years, according to the Commerce Department's National Oceanic and Atmospheric Administration (NOAA). NOAA's National Marine Fisheries Service said foreign countries harvested 3 billion pounds of fish and shellfish in 1984, compared with 2.9 billion pounds in 1983, a 4 percent increase. However, the harvest was 11 percent below the average for the preceding 5 years—3.4 billion pounds.

Meanwhile, the U.S. share of fish taken from the U.S. fishery conservation zone (FCZ) increased. It hit 50 percent of all fish taken in 1984, up from 47 percent in 1983, and the highest since the 200-mile FCZ was established in 1977. In the late 1970's U.S. fishermen were harvesting only about one-third of all the fish taken from the zone.

Altogether, U.S. fishermen landed 6.4 billion pounds of edible and industrial fish and shellfish in 1984, and about 2.9 billion pounds were caught in the FCZ. Joint venture harvests by American fishermen, who sell their catches at sea to foreign processing vessels, continued upward in 1984. Almost 1.5 billion pounds of fish, valued at $79 million, were unloaded on to foreign vessels in 1984. This represents a substantial increase over 1983 when American joint ventures sold 959 million pounds of fish worth $51.2 million. Japan continued to be the leading harvester in the U.S. conservation zone, catching 2.1 billion pounds, or 69 percent of the foreign total. South Korea, with 605 million pounds, 20 percent of the catch, was second. Other foreign fishing fleets included those from Canada, Spain, and Italy. About 97 percent of the total foreign fish harvested was taken from the Gulf of Alaska and the Eastern Bering Sea. Less than 100 million pounds were taken by foreign fishing vessels from the Northwest Atlantic.

U.S. Sets Fish Consumption Mark

Americans ate a record 13.6 pounds of seafood each in 1984, bettering the old high of 13.4 pounds in 1978, according to figures released by the National Oceanic and Atmospheric Administration (NOAA). Marketing experts with NOAA's National Marine Fisheries Service said record purchases of fresh and frozen seafood and near-record purchases of canned fish accounted for the figures.

"There's no doubt that we're eating more fish, and better quality fish, with almost every passing year," said NMFS Director William G. Gordon. "As Americans become more conscious of their health and the need for good nutrition, and as more markets open up for seafood, I expect to see these figures continue to look good for the fishing industry," Gordon added.

Other records in 1984 for the supply of U.S. seafood (domestic production plus imports) included lobster (100.1 million pounds; previous high of 92.6 million pounds in 1983), scallop meats (86.8 million pounds; previous high 71.8 million pounds in 1981), and clam meats (144 million pounds; previous high 130.1 million pounds in 1981).

Gulf Butterfish May Offer New Opportunities

Gulf butterfish, *Peprylus burti*, may be an untapped fishery resource for some trawlers according to a recent U.S.-Japanese survey. These small fish, four or five to the pound, could provide an annual yield of 47,000 metric tons according to researchers at the NMFS Southeast Fisheries Center's Pascagoula Laboratory. The best catches were made in depths of 60-80 fathoms in the spring and 100-120 fathoms in the fall.

While there is potential for a new fishery, fishermen do face problems due to product perishability, high cost of vessel conversions, and uncertainty of markets. Production and economic information is available from the Pascagoula (Miss.) Laboratory of the NMFS Southeast Fisheries Center.

Ecuadorean Shrimp Culture and Exports

Introduction

Ecuadorean shrimp farmers reported increasing difficulty in obtaining postlarvae to stock their ponds since March 1985. More recent reports from Ecuador indicate that the problem had reached crisis proportions by late summer and that an increasing percentage of the country's estimated 60,000 hectares of ponds were dry because of this shortage.

About 80 percent of Ecuador's shrimp production is farmed and it is possible that production and exports of shrimp declined 25 percent or more during the second half of 1985. Unconfirmed reports suggested that the Ecuadorean Government was considering a closed season on postlarvae collection and export of shrimp, which it may implement in 1986 to allow natural stocks to recover. If such a policy is implemented, it could have an adverse impact on that nation's shrimp shipments to the United States in 1986.

Shrimp Production

Ecuador's shrimp industry has achieved spectacular growth since 1975 because of the rapid expansion of shrimp farming. Production increased from only 5,800 metric tons (t) in 1975 to an estimated 36,600 t in 1983 (Table 1), making Ecuador the world's leading producer of farmed shrimp. Investors in Ecuador continued to build ponds in 1984, enlarging the country's capacity to culture shrimp. The Government authorized the construction of a record 24,000 hectares of new ponds in 1984 (Table 2). Although complete statistical data was not available, shrimp production in 1984 leveled off and probably declined slightly to about 32,000 t. Most of the 1984 decline was reportedly due to a poor trawler catch. Statistical data on farmed production was also not available, but most observers were probably at or slightly below 1983 levels[1]. The leveling off of the industry's growth has been primarily caused by the growers' inability to obtain adequate supplies of postlarval shrimp for stocking the ponds. The increasing tendency of some growers to raise their shrimp to larger sizes and to use lower stocking densitites may have also affected 1984 pond production.

[1]Actual statistical data is difficult to evaluate as many growers altered production data submitted to the Government in an effort to obscure various illegal practices such as under-invoicing export shipments and smuggling through neighboring countries, especially Peru.

Postlarvae Sources

Ecuadorean growers rely almost entirely on postlarvae, collected in the wild by artisanal fishermen, to stock their ponds. This dependence on wild stocks makes the growers vulnerable to shortages resulting from the seasonal availability of wild postlarvae. This problem has prompted some of the larger growers to build hatcheries. Over 30 major hatchery projects are either in operation or in various stages of construction. Unconfirmed reports indicated that more hatcheries would be constructed during the second half of 1985, and that in 1986 possibly as many as 20 would be built. Despite these ambitious plans, only a few of the functioning hatcheries are used to stock the ponds of the company which built the hatchery. Most other growers are thus still dependent on wild-collected postlarvae and are affected by the current postlarvae shortage.

Some scientists have speculated that the collection of billions of postlarvae in the wild could be affecting shrimp stocks. To date, however, no one has demonstrated that the postlarvae collection has adversely affected shrimp stocks. The Government is convinced, however, that the destruction of mangrove areas, the principal nursery habitat, has had a discernable impact on shrimp stocks.

Postlarvae Scarcity

Shrimp postlarvae off Ecuador normally become scarce each April or May

Note: Unless otherwise credited, material in this section is from either the Foreign Fishery Information Releases (FFIR) compiled by Sunee C. Sonu, Foreign Reporting Branch, Fishery Development Division, Southwest Region, National Marine Fisheries Service, NOAA, Terminal Island, CA 90731, or the International Fishery Releases (IFR), Language Services Biweekly (LSB) reports, or Language Services News Briefs (LSNB) produced by the Office of International Fisheries Affairs, National Marine Fisheries Service, NOAA, Washington, DC 20235.

Table 1.—Ecuador's shrimp production in live weight[1], 1975-84.

Year	Production (1,000 t)	Year	Production (1,000 t)
1975	5.8	1980	17.0
1976	7.6	1981	20.1
1977	9.5	1982	29.5
1978	10.0	1983	36.6
1979	12.5	1984	32.2E[2]

[1]Source: FAO "Yearbook of Fishery Statistics" for 1975-83 data and the Ecuadorean Undersecretariat of Fisheries for 1984 data.
[2]E = Estimated.

Table 2.—Ecuadorean authorization for shrimp ponds, 1980-84 (Source: Banco Central del Ecuador).

	Hectares authorized by Province					
Year	Guayas	El Oro	Manabi	Esmeraldas	Los Rios	Grand total[1]
1980	4,948	625	102	50		5,725
1981	12,992	3,578	461	456		17,487
1982	9,486	2,055	686	172		12,760
1983	10,438	876	859	372		12,544
1984	20,195	2,551	1,230	401	35	24,412
Total[1]	58,419	9,685	3,338	1,451	35	72,928

[1]Totals may not agree due to rounding. The actual area of all constructed ponds was believed to be about 60,000 hectares in late 1984.

and remain so until October or November. In 1985, the usual seasonal decline in the availability of postlarvae was unusually severe. Even early in 1985, when the postlarvae should still be normally plentiful, artisanal fishermen did not find as many postlarvae as usual. In late March and early April 1985, the availability decreased precipitously and continued to worsen. Ecuadorean scientists are not sure what caused this, but most believed that it was related to low sea temperatures.

In March 1985, abnormally cold water appeared off Ecuador and growers reported the most severe shortage of wild postlarvae ever experienced. Ecuadorean scientists measured water temperatures at 20-21°C, compared with normal August temperatures of about 24°C. This was the coldest water to appear off Ecuador for sustained periods of time in several years. The colder water has reportedly affected shrimp spawning, especially for *Penaeus vannamei* and *P. stylirostris*.

The artisanal fishermen collecting postlarvae report not only the sharply reduced availability of shrimp postlarvae in general, but especially those of the desired species. The batches of postlarvae being collected in mid-year reportedly had exceptionally low concentrations of *P. vannamei*. One estimate suggested that less than 15 percent of the postlarvae being delivered by the artisanal fishermen was *P. vannamei*, whereas the normal proportion is about 70 percent. A later report from Guayaquil suggested that the situation was worsening. Postlarvae which used to sell for $3 per 1,000 were hard to find, even at prices of $15-25 per 1,000. Ecuadorean growers were contacting hatcheries in the United States and in other countries to locate any available *P. vannamei* postlarvae.

The northernmost Provice of Esmeraldas, where seawater temperatures had stayed warmer, appeared to be an exception to the general trend. Growers report that gravid female shrimp continued to spawn and that postlarvae were still available there. Unfortunately, the shrimp stocks off Esmeraldas were not adequate to stock over 50,000 hectares of ponds. Only a few ponds had been built in Esmeraldas and its distance and isolation make it difficult to transport the postlarvae to the ponds in the south. In addition, Esmeraldas authorities attempted to prevent the transportation of postlarvae out of the province.

Ecuadorean hatchery owners were also reporting a declining availability of postlarvae. One unconfirmed report suggested that even with all the new hatcheries, postlarvae production during the first 6 months of 1985 had been lower than in 1984. The cause of this decline is unknown, but is probably at least partially related to the colder seawater temperatures. The hatcheries relying on wild-caught gravid females had been unable to continue production because fishermen were not finding any gravid females. Some hatcheries were trying to maintain production by importing nauplii to raise to the postlarval stage. Even those hatcheries doing maturation work, however, had declining postlarvae production.

Hatchery managers report a variety of problems which have affected their postlarval production. Most Ecuadorean hatcheries are located near Salinas and Manta where the quality of the seawater is ideal. Most hatcheries were not equipped to heat the water since they did not anticipate that such cold water would appear. One local observer also speculated that the colder water may have changed the composition of the algae and bacteria in the water, thus affecting hatchery production. The hatchery operators had apparently not been able to adjust to the new conditions. Those changes supposedly complicated efforts to deal with the continuing problem the hatcheries have had in controlling diseases. Some of the early 1985 decline in postlarval production was caused by a disease problem at one of the country's major hatcheries. Some observers believed that hatchery production would be sharply higher by the end of the year, but that was still far from certain.

Impact on Growers

Reports vary as to the seriousness of Ecuador's situation, but all available information suggested that the postlarvae shortage would cause a major decline in Ecuadorean shrimp exports to the United States during the second half of 1985. The March-April decline in the availability of postlarvae was only being felt by U.S. shrimp importers by summer. Growers produce shrimp on a 105- to 120-day growing cycle. Reports of unusually high numbers of dry ponds began to appear in April and May. Some growers had stocks of postlarvae in nursery ponds to stock their growout ponds, but even those supplies of postlarvae were exhausted. Shrimp exporters had reportedly been drawing on frozen shrimp inventories to maintain shipments. As a result, the impact of the postlarvae shortage was beginning to be felt in export markets by late summer.

The following information concerning the Ecuadorean situation has been obtained by the NMFS Branch of Foreign Fisheries Analysis.

Galo Bustamente of the Centro de Desarrollo Industrial[2] (CENDES) reported in June 1985 that only about 40 percent of the country's shrimp ponds were in production. Bustamente said that CENDES was cooperating with various Government and industry groups to organize a conference in Guayaquil to discuss how Ecuador's shrimp resource could best be protected.

The owner of a shrimp farm near Guayaquil claimed that his 1985 shrimp production (January-July) was about equal to production during the same period in 1984. He said, however, that as of July, 7 of his 27 ponds were dry and he believed that shipments in July and August would be off by about 10 percent; by January 1986, however, shipments could decline as much as 50 percent. He was hopeful that perhaps as early as November 1985, wild-collected postlarvae would become more available, but this would depend on several unpredictable climatic factors and, even if true, would not begin to affect export shipments until March 1985.

The manager of one of Ecuador's major shrimp companies agreed that shrimp production during the second half of 1985 would be substantially below 1984 levels. He estimated that

[2]Mention of trade names or commercial firms does not imply endorsement by the National Marine Fisheries Service, NOAA.

about 25 percent of Ecuador's ponds were dry by July 1985 and believed that production during the second half of 1985 would be about 35 percent lower than during the comparable period in 1984.

One Guayas Province grower reported in early August that over half the ponds in his area were dry and that the percentage was increasing. Growers were then harvesting the ponds stocked in March and April; only a few of the harvested ponds were being restocked.

Press reports from El Oro Province in late June 1985 indicated that some shrimp growers were closing their farms because of the postlarvae shortage. Shrimp farmers in the Province were petitioning the Government to work out a formula to supply available postlarvae from Esmeraldas Province to growers in El Oro and other provinces.

Guillermo Lasso, President of Financiera del Sur (FINANSUR), an important Ecuadorean financial institution, stated in late May 1985 that about half of the country's shrimp ponds were out of production because of the postlarvae shortage. And, an Ecuadorean Government official estimated that the export decline during the second half of 1985 would be about 20-25 percent. Shrimp is Ecuador's leading nonpetroleum export commodity and the Government has been concerned about the declining shrimp production. The official recommended that further construction of ponds be restricted until the postlarvae shortage could be resolved. He believed, however, that while 1985 might be a difficult year, natural cycles and increased hatchery production should make 1987 a "fantastic" year for shrimp growers.

Other observers report widely divergent estimates of dry ponds. Eyewitness accounts suggest that anywhere from 40-70 percent of Ecuador's ponds were dry in early August 1985. As the postlarvae were becoming increasingly scarce, this percentage was expected to almost certainly increase in September.

Another Guayas Province grower claimed that the number of dry ponds was not the only indicator of the postlarvae problem. Many growers had reportedly been stocking ponds at low densities and had stopped supplemental feeding to cut costs. As a result, yields in even those ponds still in operation may be substantially below 1984 levels.

Exports

Ecuador exports about 80-90 percent of its shrimp harvest to the United States (Table 3). Those shipments have increased from only 3,700 t in 1975 to 21,100 t in 1984 (Table 4). Ecuador has become the second leading supplier (after Mexico) to the U.S. market. Until the current postlarvae shortage began, some Ecuadorean growers were predicting that Ecuador could overtake Mexico as the most important supplier of shrimp to the U.S. market. U.S. import statistics for the first half of 1985 showed that Ecuadorean shrimp shipments to the United States totaled 10,300 t, only slightly less than the 11,000 t of shrimp received from Mexico during that period. Ecuador exports smaller amounts (about 720 t in 1984) to Japan.

Ecuadorean shrimp exports to the United States declined in 1984, the first drop since 1977 (Table 4). That decline may have been partly due to the scarcity of postlarvae, but increased smuggling through Peru may have affected the statistics, as the Ecuadorean-origin shrimp would be recorded as imports from Peru. Export shipments to the United States in 1985 fluctuated, with January and April below 1984 levels and February, March, and May above 1984 levels. June shipments were about the same in both years (Table 5). Total shipments for the first half of 1985 were about equal to 1984 shipments during that same period. A 20-35 percent decline during the second half of 1985 would have a major impact on Ecuadorean exporters—an estimated $20-30 million in export earnings could be lost.

Government Regulations

The Ecuadorean Government has been studying the solutions to the postlarvae problem. As a temporary measure, the Junta Monetaria on 30 May 1985 authorized shrimp growers to import both marine and freshwater shrimp larvae (regulation 256-85). Government agencies also initiated hatchery projects;

Table 3.—Relative importance of Ecuador's shrimp exports to the United States[1], 1975-84.

Year	Catch (1,000 t)	Exports to the U.S.[2] Amt. (1,000 t)	Percent[3]
1975	5.8	5.9	102
1976	7.6	6.7	88
1977	9.5	6.2	65
1978	10.0	8.0	80
1979	12.5	9.9	79
1980	17.0	14.7	86
1981	20.1	17.9	89
1982	29.5	26.2	89
1983	36.6	37.3	102
1984	32.2E[4]	33.8	95E

[1]Sources: FAO "Yearbook of Fishery Statistics," various years (catch data); Ecuadorean Under-secretariat of Fisheries; and Bureau of the Census, U.S. Department of Commerce (adjusted by NMFS export data).
[2]Calculated by converting the available product weight data (Table 4) to live-weight equivalents by multiplying by 1.6, the approximate conversion rate for shrimp tails to live weight. Almost all Ecuadorean shrimp exports to the United States are tails.
[3]Percentages greater than 100 result from various statistical anomalies such as the time lag between harvest and export and imprecision in calculating live-weight equivalents.
[4]E = Estimated.

Table 4.—Ecuador's shrimp exports to the United States in product weight[1], 1975-84.

Year	Exports (1,000 t)	Year	Exports (1,000 t)
1975	3.7	1980	9.2
1976	4.2	1981	11.2
1977	3.9	1982	16.4
1978	5.0	1983	23.3
1979	6.2	1984	21.1

[1]Source: Bureau of the Census, U.S. Department of Commerce.

Table 5.—Ecuadorean monthly shrimp exports to the United States by quantity (product weight), 1980-85[1].

Month	Exports (t) 1980	1981	1982	1983	1984	1985
Jan.	375	864	1,122	1,704	1,951	1,349
Feb.	548	349	533	1,210	1,589	1,882
Mar.	630	1,115	1,200	1,505	1,542	1,619
Apr.	664	855	1,125	1,865	2,082	1,803
May	851	926	1,792	2,527	1,472	1,742
June	1,068	1,237	2,009	2,382	1,729	1,792
July	675	985	1,210	2,605	2,080	NA[2]
Aug.	651	1,165	1,726	1,695	1,711	NA
Sept.	1,033	897	1,775	2,153	1,927	NA
Oct.	1,070	949	1,310	2,132	1,930	NA
Nov.	735	982	1,280	1,869	1,601	NA
Dec.	876	916	1,334	1,702	1,523	NA
Total[3]	9,160	11,220	16,383	23,300	21,138	NA

[1]These data do not include a significant, but variable, quantity of shrimp believed to have been smuggled out of Ecuador, principally through Peru, to avoid Ecuadorean currency controls. It is believed that these illegal shipments declined in 1985 as a result of changes in Ecuadorean export regulations. Source: Bureau of the Census, U.S. Department of Commerce.
[2]NA = Not available.
[3]Totals may not agree due to rounding.

the most advanced is the new Escuela Politecnica de Guayaquil (ESPOL) project at Manglaralto. Private hatchery construction is more advanced, but it will probably be several years before either Government or private hatcheries can fully supply Ecuadorean growers with postlarvae. The Government thus reportedly believes that it will have to act to safeguard wild shrimp stocks. One possible step would be to close the shrimp fishery (both collection of postlarvae and export of shrimp) during one growing season, probably for 3-4 months.

The Government has also given great attention to the emerging hatchery industry. Hatcheries now have to register with the Government, and all new hatcheries require Government authorization. New regulations place restrictions on sites, distance from neighboring hatcheries, discharges, etc. The Government has also approved new regulations giving a 5 percent tax credit to those growers who build hatcheries capable of supplying at least 50 million postlarvae per year.

Economic Impact

The impact of the postlarvae shortage on the industry remains unclear. The few growers whose maturation hatcheries are already in operation will be able to continue production. The larger companies without operational hatcheries will be adversely affected, but have the economic resources to weather a short decline in production. The companies most affected will be the newer entrants which had to pay substantially higher prices for land and have mortgages at high interest rates. Some of these companies (as well as some medium-sized companies) may fail if, as projected, export earnings declined by an estimated $20-30 million. If postlarvae failed to become more available in October-November 1985, production in 1986 could also be affected. The impact will depend on the degree of any continued scarcity of postlarvae, but a prolonged scarcity could have major repercussions on these companies. Smaller growers who have built ponds on their farms will probably be able to survive as they have other crops and are not completely dependent on shrimp farming.

Hatchery Industry

The most significant impact of the 1985 postlarvae shortage may be on the hatchery industry. The cost of building a small hatchery capable of producing 10-15 million postlarvae per month ranges from $0.8-1.0 million. This cost and the previously inexpensive supply of wild-caught postlarvae discouraged most growers from investing in hatcheries. The first hatcheries proved expensive for the growers that invested in them. It cost about $4-5 to produce 1,000 postlarvae, while artisanal fishermen were able to deliver postlarvae for about half that amount. The 1985 shortage of postlarvae has convinced virtually all major shrimp growers of the need to build hatcheries.

The increasing price of postlarvae has also changed the economics of hatchery investments. At $3 per 1,000 postlarvae, hatcheries were not an attractive investment, given the many technical difficulties associated with their operation. At 1985 prices of $15-25 per 1,000 postlarvae, many investors were increasingly viewing hatcheries as profitable investment opportunities. One estimate suggests that it still costs about $4-5 to produce 1,000 postlarve. Many hatchery managers believe that they can eventually lower those costs. But even with costs of $5 per 1,000 postlarvae, hatcheries with postlarvae to sell could turn a significant profit. As a result, the 1985 shortage should, in the long run, serve as a powerful stimulus to the already booming Ecuadorean hatchery industry.

Forecast

Prospects for 1986 were uncertain. Much will depend on climatic factors such as sea temperatures and precipitation which cannot be predicted. Growers were hoping that wild-caught postlarvae would begin to become more available in October or November 1985. If this happened, shrimp harvests at near normal levels could be resumed by February or March 1986. Because many additional ponds have been built since 1983, harvests above 1983 levels are theoretically possible. While postlarvae usually begin to appear in increasing quantities during late October or early November, it was far from certain they would in 1985. If cold water continues to persist off the coast, the scarcity of postlarvae may continue for some time. If so, Ecuadorean production could continue to decline and 1986 shipments could be below 1985 levels. It is unlikely that the many new hatcheries will yet be able to fully supply growers if the scarcity of wild-collected postlarvae continues in 1986. Industry sources continue to stress, however, that with over 60,000 hectares of shrimp ponds, Ecuador could produce about 70,000 t of shrimp per year if adequate supplies of post larvae were available. (Source: IFR-86/50R1.)

Norway's 1984 Fish Catch Down; Exports, Value Up

Although the total 1984 Norwegian fish and shrimp catch was 14 percent below 1983 (2.5 million vs. 2.9 million t), fish and shellfish exports, other than round-frozen capelin roe, mackerel, and Greenland halibut, reached US$254 million. The total export value was US$288 million, up from US$255 million in 1983, according to the Norwegian Information Service (Norinform).

Overall, the herring fisheries (capelin, herring, brisling, mackerel, Norway pout, blue whiting, etc.) dropped 18 percent, and the cod fisheries were down from 1983 by slightly over 3 percent. Of the main fisheries groups, only shellfish showed a catch increase (slightly over 9 percent) in 1984, owing to larger shrimp catches.

Capelin

Capelin, however, was the main reason for the overall catch decline. Reduced reserves and more stringent quotas brought the capelin catch down 36.7 percent to 944,000 t from 1,492,000 t in 1983. In 1983, capelin accounted for more than 50 percent of the total Norwegian catch, but in 1984 its share was just 37.4 percent.

The cod catch, 263,000 t, was down 7 percent from 1983. In value, the cod fisheries are decidely Norway's most

important at US$111 million, more than US$33.3 million above the value of shrimp and capelin. The 1984 shrimp catch reached 82,000 t, a 9.3 percent increase over 1983 and the value rose by 10.7 percent to US$80.2 million. That made the shrimp fishery Norway's second most important, as capelin dropped to third place.

Exports

In 1984, 21,000 t of saithe and 19,888 t of Atlantic salmon were exported, a 26 percent increase. Other export figures were 25,000 t of shrimp, 5,700 t of akkar (small octopus), 4,400 t of haddock and cod, and 550 t of plaice. Redfish exports almost doubled, reaching 81 t. Norwegian fish were exported to 32 countries, the biggest customer being West Germany with 11,900 t.

Aquaculture

The Norwegian fish culture industry exported goods valued at over US$122 million. In 1984, Atlantic salmon was the most important at 22,000 t or 30 percent more than 1983. Over 90 percent of Norwegian salmon is exported. The EEC was the most important market but exports to the United States increased at the greatest rate. Last year saw a doubling of Atlantic salmon exports to the United States.

The first-hand value of Norway's salmon and trout for 1984 was US$106 million, US$22 million more than in 1983. However, some fish farm facilities are experiencing disease problems. In Lofoten, in north Norway, a disease called "Hitra" has caused large losses for the producers and there are fears that it could spread northward.

The Fisheries Directorate's Ocean Research Institute in Bergen is studying fish disease problems and has produced important results. A treatment for salmon louse helped large sectors of the industry. Also, a serum for vibriosis has been prepared, while progress has been made in combatting acid water. Salmonid hatchery techniques have been improved, and a method was developed in 1983 for the farming of cod. During 1984, 120,000 young cod were produced, but too little is yet known about environmental conditions during their early years.

However, Institute Professor Dag Møller believes that the Norwegian fish-farming industry is too narrow and vulnerable. He says that hatchery systems which reduce mortality, a comprehensive campaign against fish diseases, and, not least, the development of new farm fish species such as halibut, plaice, turbot, lobster, clams, and oysters will be the most important tasks in the time ahead.

The Future

Norwegian fisheries prospects in the next few years are reportedly better than they have been for a long time, mainly because the reserves of some of the most important species show considerable growth. After the recent difficult years of scant resources and strict quota regulations, there are now grounds for optimism, says Minister of Fisheries Thor Listau.

Reserves of Norwegian Arctic cod and haddock are clearly increasing. The International Oceanographic Research Council recommended a small increase in the quotas for those species in 1985, and indicated substantial increases in later catch quotas. Catch quotas of 300,000 t in 1986 and 600,000 t in 1987 have been proposed for the Norwegian Arctic cod, and corresponding proposals for haddock were 100,000 t and 180,000 t.

Norwegian herring reserves are also increasing. Recent studies on the RV *G.O. Sars* in the Barents Sea indicate that stocks in the area are equal to more than 6 million hectoliters. Similar studies were carried out last year and the scientists say that the trend is very positive. Although some herrings are caught in the capelin fisheries, they survived the winter of 1984 very well. The 1983 year class is the most vigorous of the Norwegian spring spawning herring for the past 20 years researchers maintain.

Latin American Fisheries, 1984

All major Latin American fishing countries except Argentina reported improved fish catches in 1984. Latin American fishermen caught 10.8 million metric tons (t) in 1984, up 19 percent over the 9.0 million t taken in 1983 (Fig. 1). The 1983 catch was severely depressed by the 1982-83 El Niño event in the Eastern Pacific, one of the most devastating such events ever recorded.

All of the major countries most affected by El Niño (Chile, Peru, Ecuador, and Mexico), reported sharp catch increases in 1984. The 1984 catch was not far below the 11.3 million t catch of 1982, the largest fisheries catch reported by Latin American countries since the collapse of the Peruvian anchovy fishery in 1972. Fishery officials in many of these nations believed that the 1985 catch would be as large or even larger than the 1984 catch. The most important developments in the six largest Latin American fishing countries are given below.

Chile

Chile is Latin America's most important fishing country (Table 1). Chilean fishermen reported substantial catch increases in both 1982 and 1983. The country's catch did not decline after the 1982-83 El Niño, but Chilean scientists are still concerned about the long-term impact of the event.

Chilean companies have made major investments in recent years. They have had to adjust to the decline of the anchovy fishery by redirecting fishing efforts to sardine and mackerel stocks. Private fishing companies have made the necessary changes in vessels, gear, and strategy with little or no assistance from the Chilean Government. Many vessels added to Chile's growing fleet have been used vessels bought from hard-pressed

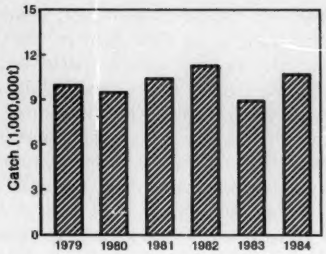


Figure 1.—The Latin American fisheries catch, 1979-84.

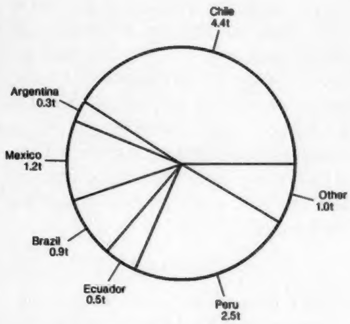


Figure 2.—The 1984 Latin American fisheries catch by major nation in millions of metric tons.

Table 1.—Latin America's fisheries catch, 1980-84.

Country or dependency	Catch (1,000 t) 1980	1981	1982	1983	1984[1]	Major species
Caribbean						
Antigua	1.6	1.8	2.0	2.2		
Bahamas[2]	5.0	4.4	4.7	5.2		Lobster
Barbados	3.7	3.4	3.5	6.5		
Bermuda[2]	4.1	1.9	2.2	0.5		
Brit. Virgin Isl.	0.3	0.3	0.3	0.3		
Cuba	186.5	164.8	195.2	198.5	198.0	Lobster
Dominica	1.4	1.5	1.5	1.5		
Dominican Rep.	10.7	12.0	13.2	13.2		
Grenada	1.8	1.7	1.8	1.8		Flying fish
Guadeloupe	8.0	8.3	8.8	8.7		Mackerel
Haiti	4.0	4.0	4.0	4.0		
Jamaica	9.1	7.8	7.9	8.7		
Martinique	4.7	4.7	4.7	4.7		
Montserrat	0.1	0.1	0.1	0.1		
Netherl. Antilles	1.9	1.8	1.8	1.9		
Puerto Rico	2.6	2.7	2.2	2.2		
St. Kitts	1.9	1.9	1.9	1.9		
St. Lucia	2.4	2.4	2.4	2.6		
St. Vincent	0.5	0.5	0.5	0.5		
Trinidad-Tobago	4.5	4.5	4.5	4.5		Mackerel
Turks and Caicos	1.1	1.1	1.1	1.1		Lobster/conch
U.S. Virgin Isl.	0.7	0.8	0.9	0.8		Mackerel
Subtotal	256.6	232.2	265.2	271.2	270.7E[3]	
Central America						
Belize	1.3	1.3	1.4	1.5		Lobster/conch
Costa Rica	14.9	12.6	10.9	10.9		Tuna/shrimp
El Salvador	14.0	20.3	13.5	7.6		Shrimp
Guatemala	3.5	4.3	4.3	4.3		Shrimp
Honduras	6.4	6.3	5.0	8.4		Lobster
Mexico	1,222.5	1,536.2	1,323.9	1,070.0	1,219.0	Shrimp/tuna
Nicaragua	7.0	5.9	5.0	4.5		Shrimp/lobster
Panama	216.4	149.5	112.9	166.1	113.5	Shrimp/anchovy
Subtotal	1,486.0	1,736.4	1,476.9	1,273.3	1,369.7E	
South America						
Argentina	385.3	359.6	475.0	416.3	260.0E	Hake/shrimp
Bolivia	4.4	5.6	5.6	5.6		
Brazil	819.8	828.7	828.9	844.5	875.0E	Lobster/shrimp
Chile	2,816.7	3,385.4	3,673.0	3,978.1	4,445.0	Sardine/mackerel
Colombia	76.2	94.7	71.4	57.5	80.6	Shrimp
Ecuador	643.5	731.0	654.1	307.3	500.0E	Shrimp/tuna
French Guiana	1.1	1.2	1.5	1.4		Shrimp
Guyana	26.6	23.4	25.8	27.6		Shrimp
Paraguay	3.3	3.4	3.4	3.5		
Peru	2,734.0	2,740.3	3,484.0	1,486.8	2,500.0E	Sardine
Suriname	3.0	3.4	2.9	3.6		Shrimp
Uruguay	120.4	147.0	119.1	144.1	129.0	Hake/croaker
Venezuela	186.6	191.9	212.4	226.9	280.1	Shrimp/tuna
Subtotal	7,820.9	8,515.6	9,552.1	7,503.2	9,111.4E	
Grand total	9,563.5	10,484.2	11,294.2	9,047.7	10,751.8E	

[1]1984 data are available only for major countries. For other countries, 1983 data were used to obtain the totals and an indication of general trends.
[2]These islands are not physically located in the Caribbean, but are included in the Caribbean totals for organizational simplicity.
[3]E = Estimated by the NMFS Foreign Fisheries Analysis Branch.

Peruvian fishermen. The Chilean Government has promoted diversification of the industry and several interesting programs are underway, including demersal trawling off the southern coast, krill fishing with the Japanese, and various salmon and molluscan culture projects. The industry remains, however, dominated by the northern reduction industry.

Peru

Peruvian fishermen reported the largest 1984 catch increase of any Latin American country. Small pelagic stocks recovered sharply from the 1982-83 El Niño event. The El Niño and associated climatic and meteorological disturbances caused widespread destruction in coastal communities, damaging piers and other shore installations as well as roads and bridges needed to transport the catch. The fishing industry is still recovering from that damage as well as adjusting to changes in species composition.

Unlike Chilean fishermen, Peruvian fishermen have not made the changes necessary to utilize the much larger mackerel stocks now found off Peru. The Instituto del Mar believes that the mackerel biomass may be as much as 9 million t. Those stocks are now being fished by the Soviet Union and other communist countries outside the 200-mile zones of Peru and Chile.

Peru's fishing industry is still dominated by the fishmeal industry which was nationalized in 1973. The Ministry of Fisheries has, for several years, financed the massive budget deficits reported by the state-owned fishmeal company (PESCA PERU), but administrative

changes implemented by Fisheries Secretary Ismael Benavides have at last enabled PESCA PERU to become profitable. Peru's canning industry continues to report serious economic difficulties caused by the weak international market for canned sardines. Some companies are reporting considerable success with the new fishery for scallops and the developing shrimp culture industry in northern Peru.

Mexico

Mexican fishermen reported a moderate catch increase in 1984. Much of the increase resulted from improved pelagic catches along the Pacific coast. Included in the 1984 total was a record tuna catch of over 80,000 t. Mexico launched the second phase of its major effort to develop the fishing industry which was begun in 1977.

Development Plan

The current 5-year National Fisheries and Marine resources development Plan (1984-88) is a much more modest plan than the original 1977-82 plan because of the country's fiscal crisis which began in 1982. Under the latest plan, the Government hopes to increase the fisheries catch from 1.1 million t in 1983 to 2.5 million t by 1988. Major expansion is planned for the state-owned fishing company, Productos Pesqueros Mexicanos.

Most of the important fisheries continue to be reserved for the country's cooperative fishermen. Private investors, however, would like to see the regulations governing the cooperatives changed to allow more direct private investment (such changes are being studied by the Congress). The Government estimates that the development plan should enable Mexico to increase export earnings from $570 million in 1984 to $690 million by 1988. Some observers, however, point out that long-term trends in Mexican exports are unclear.

Shrimp

Shrimp is Mexico's leading fisheries export commodity. It is not yet known if Mexico could significantly expand its shrimp trawler catch. Many observers believe that shrimp stocks, especially those that support the more important Pacific coast fishery, are already being utilized at or near capacity. Mexico could conceivably increase shrimp production and exports by culturing shrimp, but legal constraints which prevent private individuals from culturing shrimp have restricted the industry's development. Perhaps more importantly, the expanding production of cultured shrimp and other market factors have caused a substantial decline in shrimp prices since early 1983. If prices remain low, Mexico will have difficulty meeting its export target of $690 million by 1988. Other important export-oriented fisheries also face serious problems. Mexico continues to report difficulty exporting tuna, while abalone and lobster resources reportedly are declining.

Brazil

Brazilian fishermen reported a small catch increase in 1984. Many companies, however, reported sharply higher earnings as a result of increased shrimp and lobster catches and exports. Brazilian scientists believe that both fisheries, especially the lobster fishery, were affected by the prolonged drought in northeastern Brazil. The 1984 rains reportedly resulted in increased catches.

Exports to the United States, Brazil's major market, totaled $132 million in 1984, a 30 percent increase over the $97 million shipped in 1983. Brazil continues to attract foreign shrimp and tuna fishermen through various joint venture and leasing arrangements. The Government believes that one of the most promising prospects lies in the developing shrimp culture industry. Officials believe that shrimp culture may eventually emerge as a major component of the country's fishing industry and has authorized over $13 million in loans for various shrimp culture projects. The Government is currently administering the second largest fisheries development program underway in Latin America. The $130 million program is partially financed by the Inter-American Development Bank.

Ecuador

Reports from Ecuador are incomplete, but fishermen did report much better catches in 1984 than in 1983, especially for small pelagic species and tuna. The country's most important fishery is shrimp, most of which is cultured. Shrimp trawler fishermen reported lower 1984 catches and most shrimp farmers reported production at or slightly below 1983 levels. The principal problem faced by the shrimp farmers reportedly was a shortage of postlarvae to stock the ponds. Many companies are now planning hatcheries to guarantee a reliable source of postlarvae. It will probably be several years, however, before hatcheries will supply a sizeable proportion of the approximately 24 billion postlarvae that growers need annually. Many farmers reported reduced profit margins as a result of spiraling production costs. Industry spokesman are also disappointed that the new Government had not made many changes that had been hoped for in fiscal and export policy.

Argentina

Argentina has one of the worlds' largest underutilized fisheries resource. The Government's fisheries development program, however, has been complicated by continuing difficulties with the United Kingdom over the Falkland Islands. The British maintain a 150-mile Exclusion Zone around the Falklands, restricting both Argentine fishermen and Argentine efforts to limit foreign fishing in the area.

The extensive foreign fishing, which has expanded since 1982, has been especially harmful to Argentina. Many countries fishing in the South Atlantic, especially Poland, market their catch on the international market in competition with Argentine companies. As a result, there has been a substantial decline in the prices received by Argentine exporters. Several Argentine companies, faced with declining export prices and spiraling domestic costs, have had to close. The one bright spot for Argentina has been the rapid growth of the shrimp fishery along the central coast. Several companies report that only the profits obtained in the shrimp fishery have allowed them to continue to operate. (Source: IFR-85/15.)

New NMFS Scientific Reports Published

Some publications listed below may be sold by the Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402. Copies of all are sold by the National Technical Information Service, Springfield, VA 22151. Writing to either agency prior to ordering is advisable to determine availability and/or price (prices may change and prepayment is required).

NOAA Technical Report NMFS 26. Darcy, George H. **"Synopsis of biological data on the sand perch, *Diplectrum formosum* (Pisces: Serranidae)."** March 1985, iv + 21 p., 20 figs., 7 tables.

ABSTRACT

Information on the biology and fishery resources of a common western Atlantic serranid, *Diplectrum formosum*, is compiled, reviewed, and analyzed in the FAO species synopsis style.

NOAA Technical Report NMFS 27. Sindermann, Carl J. (editor). **"Proceedings of the Eleventh U.S.-Japan Meeting on Aquaculture, Salmon Enhancement, Tokyo, Japan, October 19-20, 1982."** March 1985, iii + 102 p. (15 papers.)

NOAA Technical Report NMFS 28. Perrin, William F., Michael D. Scott, G. Jay Walker, and Virginia L. Cass. **"Review of geographical stocks of tropical dolphins (*Stenella* spp. and *Delphinus delphis*) in the eastern Pacific."** March 1985, iv + 28 p., 26 figs., 4 tables, 2 app.

ABSTRACT

Information on geographical variation is reviewed for *Stenella attenuata*, *S. longirostris*, *S. coeruleoalba*, and *Delphinus delphis* in the eastern tropical Pacific, and boundaries for potential management units are proposed. National Marine Fisheries Service and Inter-American Tropical Tuna Commission sighting records made from 1979 to 1983 which were outside boundaries used in a 1979 assessment were examined for validity. Tagging returns and morphological data were also analyzed. Several stock ranges are expanded or combined. Three management units are proposed for *S. attenuata*: the coastal, northern offshore, and southern offshore spotted dolphins. Four management units are proposed for *S. longirostris*: the Costa Rican, eastern, northern whitebelly, and southern whitebelly spinner dolphins. Two provisional management units are proposed for *S. coeruleoalba*: the northern and southern striped dolphins. Five management units (two of which are provisional) are proposed for *D. delphis*: the Baja neritic, northern, central, southern, and Guerrero common dolphins. Division into management units was based on morphological stock differences and distributional breaks.

NOAA Technical Report NMFS 29. Moser, Mike, Judy A. Sakanari, Carol A. Reilly, and Jeannette Whipple. **"Prevalence, intensity, longevity, and persistence of *Anisakis* sp. larvae and *Lacistorhynchus tenuis* metacestodes in San Francisco striped bass."** April 1985, iii + 4 p., 6 figs.

ABSTRACT

Thirteen hundred and seventy-three striped bass, *Morone saxatillis*, were collected from the San Francisco Bay-Delta area to correlate host diet with parasitic infections and to determine the prevalance, intensity, longevity, and persistence of larval *Anisakis* sp. nematodes and the metacestode *Lacistorhynchus tenuis*. There is an increase in the prevalence and intensity of *Anisakis* sp. and in the intensity of *L. tenuis* with increase of age of the host. These increases are probably related to the diet and the persistence of the parasites. The infections of both species are overdispersed. San Francisco Bay striped bass are an incompatible host for both species of parasites. Degenerated *Anisakis* sp. will remain in the host for at least 8 months and *L. tenuis* metacestodes for 22 months. The occurrence of several other species of parasites and a tumor are also reported.

NOAA Technical Report NMFS 30. Shumway, Sandra E., Herbert C. Perkins, Daniel F. Schick, and Alden P. Stickney. **"Synopsis of biological data on the pink shrimp, *Pandalus borealis* Krøyer, 1838."** May 1985, iv + 57 p.

ABSTRACT

This synopsis of the literature was designed to summarize the biological and biochemical studies involving *Pandalus borealis* as well as to provide a summary of the literature regarding the fisheries data published before early 1984. Included are many unpublished observations, drawn from studies at the State of Maine Department of Marine Resources Laboratory in West Boothbay Harbor, Maine.

NOAA Technical Report NMFS 31. Anderson, Emory D., John G. Casey, John J. Hoey, and W. N. Witzell. **"Shark catches from selected fisheries off the U.S. east coast."** July 1985, iv + 22 p., 3 figs., 25 tables.

CONTENTS

Included are three articles: "Analysis of various sources of pelagic shark catches in the Northwest and Western Central Atlantic Ocean and Gulf of Mexico with comments on catches of other large pelagics" by Anderson; "Estimated catches of large sharks by U.S. recreational fishermen in the Atlantic and Gulf of Mexico" by Casey and Hoey; and "The incidental capture of sharks in the Atlantic United States Fishery Conservation Zone by the Japanese tuna longline fleet" by Witzell.

Improving Habitat for Fish and Anglers

"Artificial Reefs," edited by Frank M. D'Itri, has been published by Lewis Publishers, Inc., 121 South Main Street, P.O. Drawer 519, Chelsea, MI 48118. The book, with both marine and freshwater applications, is divided into four parts: I, physical and limnological characteristics of artificial reefs; II, reef design and construction; III, artificial reef ecology; and IV, legal, economic, regulatory, and organization considerations in reef siting and construction. Overall, the 25 papers serve as an excellent overview of the history, current state-of-the-art, and future prospects for man-made reefs.

In Part I, papers review the history of artificial reefs in the United States, enhancement of the marine environment

for fisheries and aquaculture in Japan, the ecology of natural shoals in Lake Ontario and their importance to artificial reef development, physical and geological aspects of artificial reef site selection, and the physical and limnological characteristics of natural spawning reefs in western Lake Erie.

Many of the earlier reports on artificial reefs were often unpublished or published individually or in a "proceedings" volume with limited availability. This book, however, updates several of those studies and makes the data easily available to students, biologists, researchers, fisheries managers, etc.

Part II includes papers on the planning of artificial reefs in Japan, recent approaches in artificial reef design and applications, reviews of artificial reef programs in Hawaii, Virginia, and Lake Michigan; the use of scrap tires and fly ash from coal combustion for reef building; and a review of mid-water fish aggregating devices (FAD's).

Part III, ecology, presents an update on the Smith Mountain Lake, Va., artificial reef project, and discussions of enhancement of fisheries habitat and urban recreational fishing; density estimates of warm-temperature reef fishes associated with an artificial reef, a natural reef, and a kelp forest; a study of the biota, especially prey species, of naturally rocky area of southwestern Lake Michigan and what it means for artificial reef construction; and preliminary studies of an artificial reef as a fishery management strategy in Lake Michigan.

Part IV includes discussions of Federal responsibilities or approaches to regulating artificial reefs, sport fishing needs for artificial reefs, the economic impact of artificial reefs on Great Lakes sport fisheries, and a review of Florida's artificial reef network and strategies that could enhance user benefits. The 589-page hardbound volume is available from the publisher for $49.95.

Meanwhile, the Artificial Reef Development Center, administered by the Sport Fishing Institute, 1010 Massachusetts Ave., N.W., Suite 100, Washington, DC 20001, has initiated a very useful Technical Report Series on various aspects of artificial reef construction, maintenance, etc.

The first Technical Reports Series 1 (24 pages), is **"Permitting Procedures for Artificial Reefs"** by Richard T. Christian, which provides an overview of the legal authorities of the various governmental agencies and their extent of involvement in permitting artificial reefs. It presents a step-by-step guide to the procedures that lead to the acquisition of the required permits for reef construction.

The second is **"Artificial Reef Maintenance"** by DeWitt O. Myatt (30 pages, 5 appendices), and is an excellent guide to long-term planning for the care and maintenance of the reefs, especially the buoys and markers which the U.S. Coast Guard classifies as "special purpose aids to navigation."

Number 3, **"Liability Concerns in Artificial Reef Development"** by Patricia R. Collins (26 pages, 1 appendix), deals with what has been a major constraint to some reef plans. There is little case law on the topic and the author presents a number of suggestions for such concerned parties as material donors, reef contractors, volunteer transporters, permittees, and involved agencies; a discussion of the National Fishery Enhancement Act of 1984 also addresses many of the concerns.

Report 4 is **"Transportation Costs of Artificial Reef Materials"** by Richard T. Christian (19 pages), and recent data is presented from projects in 17 states. Transportation accounts for about 75 percent of reef deployment costs, and depends on the type and amount of material, which also impinges on the type of transportation required. Potential funding sources are also discussed. Report prices vary and they are available from the Institute's Center.

A Review of the Seaweeds of China

China's coastline (18,000 km mainland and 14,200 km islands) harbors about 1,000 species of seaweeds over zones ranging from tropical to warm temperate. And the Chinese are among those who actively utilize seaweeds for food and medicine. At present, 45 genera representing a little over 100 species are of economic value in that nation, being used for food, medicine, fertilizer, and as the raw material for industrial production of phycocolloids (i.e., agar, algin, and carrageenan) and other products such as mannitol and iodine. Indeed, records of the occurrence of *Porphyra* and its food value appeared in a Chinese book published sometime between 533 and 544 A.D.

Now, **"Common Seaweeds of China,"** has been published by the Science Press, Beijing, China, in honor of the XIth International Seaweed Symposium held in Quingdao in June 1983. The handsomely printed volume, a cooperative work by several phycologists, was edited by C. K. Tseng, Research Professor of Marine Biology, Institute of Oceanology, Academia Sinica, Quingdao, and it should serve as an excellent guide to the common marine flora of that region.

Described are 512 species of Chinese seaweeds, including 66 species of the Cyanophyta, 226 species of the Rhodophyta, 1 species of the Xanthophyta, 115 species of the Phaeophyta, 1 species of the Prochlorophyta, and 103 species of the Chlorophyta. Each species described is illustrated with excellent color photographs (mostly made in the natural habitat) and, in some cases, with detailed drawings and micrographs where needed to highlight particular details. However, a few common species were not shown owing to a lack of suitable specimens, and, since the volume is not all-inclusive, there are no keys to the genera and species.

The book begins with a systematic list of species and then presents "ecological photographs" of various species in their natural habitats and scenes of seaweed harvesting and culture. Then follow the plates and descriptions of the 512 species, a selected bibliography, and an index.

Descriptions of the seaweeds include external morphology, color, texture, habitat, occurrence in China, geographical distribution, and internal structure and reproductive characteristics (when needed for identification). Also given are the uses of economically valuable seaweeds.

The hardbound 316-page volume is distributed and sold for $125.00 by Kugler Publications, P.O. Box 5794, Berkeley, CA 94705, or, in The Netherlands, by Kugler Publications BV, P.O. Box 516, 1180 AM, Amstelveen, The Netherlands.

MANAGEMENT OF WILD SALMONIDS

"Proceedings of the Olympic Wild Fish Conference," edited by J. M. Walton and D. B. Houston, has been published by the Fisheries Technology Program, Peninsula College, 1502 E. Lauridsen Blvd., Port Angeles, WA 98362. In this case, "wild fish" refers to the salmonids of the genus *Oncorhynchus* and *Salmo* of the Pacific coast. The editors note that some of these wild stocks have been either neglected, managed, or mismanaged almost to the verge of extinction, and the conference was held so fisheries managers and scientists could present their current management strategies, research findings, and agency philosophies, exchange ideas, and discuss and evaluate critical issues. Those objectives were attained to a surprising degree, with many of the papers providing interesting and sometimes provocative ideas from a variety of perspectives.

The volume is divided into seven major sections: Genetic differentiation of wild fish stocks, lake studies and management strategies, agency management of wild fish stocks, the cutthroat trout, coho and chinook salmon, steelhead trout, and one on "perspectives." The latter contains thoughtful papers on the "Social value of wild fish" by J. T. Martin, and Bill McMillan's review of "An angling community in change," a look at one stream's 25 years of change from a native steelhead fishery to a hatchery-dominated fishery, and the effects on angling techniques and ethics.

In the first section are discussed the concept of a salmonid stock and the methods used to differentiate stocks and problems in gene resource conservation by J. D. McIntyre. Fred Utter et al. discuss the genetic characterization of populations in the southeastern range of sockeye salmon; R. R. Reisenbichler reviews "outplanting," releasing hatchery fish at remote localities, and its potential for harmful genetic change in naturally spawning salmonids. J. H. Helle discusses "gene banks" for wild salmonid stocks and L. A. Riggs presents a scenario for genetic resource management of salmon and sea-run trout.

The second section presents discussions on management strategies for restoration and rehabilitation of sockeye salmon in Lake Ozette, Wash., the early exploitation and current status of trout in Lake Crescent, Wash., and management prescriptions and classification of the lake fishery on Vancouver Island, B.C. The third section presents discussions of the preservation of spring chinook in Puget Sound, Wash.; status and management of anadromous fish in Olympic National Park; James M. Johnston provided an administrator's perspective of wild stock management; and G. S. Morishima provided a look at the inherent problems and tradeoffs involved in or impinging on wild fish management.

And, the fourth through the sixth sections present papers on status, life history studies, habitat utilization, spawning strategies, and management programs for several stocks of cutthroat trout, coho and chinook salmon, and steelhead trout. In sum, the proceedings present a good look at several important if sometimes controversial aspects of the protection and management of wild salmonids. Copies of the 308-page paperbound volume are available from J. M. Walton at the Peninsula College for $15.00.

Soviet Volume on Marine Productivity Translated

"Oceanology: Biology of the Ocean. Volume 2. Biological Productivity of the Ocean," M. E. Vinogradov, editor-in-chief, has been translated into English and published as NOAA Technical Memorandum NMFS-F/NEC-34. Paper copies or microfiche are available from the National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161 (write NTIS for current prices).

Initially published by Nauka Press, Moscow, in 1977, the volume was translated by Albert L. Peabody of the NMFS Foreign Language Services Branch. The English Version Editor was Ken Sherman, Director, NMFS Narragansett (R.I.) Laboratory, and Russian scientists cooperated in reviewing and correcting versions of the English translation.

Part 1, "Ecology of Marine Communities," includes chapters on the ecological concepts, the structure and development of pelagic, benthic, and coral reef communities in different global regions from several viewpoints, including the adaptive significance of schooling in the sea. Primary and secondary production is discussed, as are ecosystem models.

Part 2 focuses on "Human Activity" with a discussion on the potentials for increasing yields from fishery resources in Chapter I and the actual and potential impacts of pollution on marine ecosystems in Chapter II. Altogether, the volume represents an extensive synthesis of Soviet literature dealing with marine ecosystems which is discussed in relation to contemporary ideas of marine ecologists in other countries. An extensive listing of references in Russian and English which supports the synthesis is included.

Methods of U.S. Shellfish Culture

"Crustacean and Mollusk Aquaculture in the United States," edited by Jay V. Huner and E. Evan Brown, has been published by Avi Publishing Company, 250 Post Road East, P.O. Box 831, Westport, CT 06881 (stock no. 443). In its 10 chapters, various authorities review the status, biology, and culture of such species as crawfishes, freshwater prawns, penaeid shrimps, homarid lobsters, other crustaceans (blue and cancer crabs, spot prawn, spiny lobsters, and smaller shrimps), oysters (American, Pacific, European, and Olympia), clams (hard, manila, butter, littleneck, softshell, and surf clams), mussels, and

abalone. The tenth chapter discusses water quality—physical, chemical, and biological variables and pesticides and water analysis—for culture systems. In addition, it presents a short appendix on the life cycle, culture, and utilization of the brine shrimp, *Artemia*.

Many factors influence the commercial profitability of shellfish culture operation in the United States. Most of the species discussed are valued relatively high among seafoods, although a few are also used as bait. However, only the freshwater crawfishes and oysters have yet been cultured on a profitable, large-scale basis within the United States. Several of the others, however (i.e., penaeid shrimps, abalones, and mussels), are cultured profitably elsewhere.

For each species or group is discussed basic biology (life cycles, reproduction, growth, food habits), genetics, environmental requirements, diseases and parasites, culture methods, processing, economics, hatcheries (where applicable), and the current status and future of the species' culture in the United States. Several species are suggested as candidates for expanded culture programs. Each chapter provides a good, succinct review of each species' culture and the volume should be a useful reference for those interested in shellfish culture. Indexed, the 476-page hardbound volume is available from the publisher for $59.00.

The Marine Fishes From Indonesia to Australia

"Trawled Fishes of Southern Indonesia and Northwestern Australia," by Thomas Gloerfelt-Tarp and Patricia J. Kailola, has been published by the Australian Development Assistance Bureau, the Directorate-General of Fisheries, Indonesia; and the German Agency for Technical Cooperation. The volume is an excellent inventory of the ichthyofauna obtained by trawling in the waters from northwestern Australia through the island regions of Timor, Bali, Java, and Sumatra, during a regional fishery assessment project, JETINDOFISH, the Joint Eastern Tropical Ocean Fishery Study from 1979 to 1981. Most trawling was done between 20 and 250 m, although considerable work was done close to coral reefs.

Altogether 1,266 sharks, rays, and bony fishes are described, encompassing 179 families. More than 130 of those species had not been recorded before from either Indonesia or Australia, and about 90 were new to science. The text provides identification guidelines and generic synopses to accompany the 950 color photographs and about 232 drawings. Indonesian and English names are provided for the families, and references to appropriate literature are cited for each family. Identification data accompany each photo or illustration. Also included are drawings of fish anatomy and a glossary of terms utilized in fish identification.

A 60-page species list provides data on the author and date of description, capture locality and distribution details, area from which all recorded specimens were obtained, and other pertinent data. General and specific references are listed in a 19-page bibliography. For many fishermen and scientists working on or with fishes of the region, the volume will be a handy reference. Inquiries on the availability of the 406-page volume should be directed to either: Heng, S.U. Pte. Ltd., Tong Lee Building, Block A, 35 Kallang Pudding Road 02-12, Singapore 1334; or The Indonesia Section, S.E.A.P. Branch, Australian Development Assistance Bureau, G.P.O. Box 887, Canberra, A.C.T. 2601, Australia.

ICLARM Reports on Tropical Fisheries

ICLARM, the International Center for Living Aquatic Resources Management, MCC P.O. Box 1501, Makati, Metro Manila, Philippines, publishes several series of excellent reviews, technical reports, studies, proceedings, bibliographies, etc. Number 8 in the ICLARM Studies and Reviews series is **"Fish Population Dynamics in Tropical Waters: A Manual for Use With Programmable Calculators"** by Daniel Pauly.

Chapter by chapter, the author applies to tropical and subtropical fish and fisheries methods covering length-weight relationships, mesh selection, growth, mortality, population size estimation (e.g., by tagging, virtual population analysis), yield-per-recruit assessments, stock-recruitment relationships, surplus-yield models, the rate of increase of populations, and aspects of multispecies stocks and fisheries. The program listing the user instructions of 30 programs for a programmable calculator are included, and the translation of those programs for use with other types of calculators is discussed. Sixty computational examples, including complete keystroke sequencees, are provided to illustrate the methods presented in the text. Included also is a list of symbols and their definitions, references, an author index, and a program card hold. The paperbound volume costs $25.00 (airmail) and the hardbound volume is $29.50 (airmail). U.S. orders through ISBS should include $2.25 postage.

Number 7 in the same series is **"Caribbean Coral Reef Fishery Resources,"** edited by J. L. Munro. The volume constitutes the full 18-part series originally published as No. 3 in the series Research Reports from the Zoology Department, Univesity of the West Indies," plus an epilogue reviewing progress in coral reef fisheries research from 1973 to 1982. Following an introductory review of the Caribbean reef fisheries by Munro, are chapters on the Jamaican fishing industry, areas investigated and objectives and methods, and the composition and magnitude of line and trap catches in Jamaican waters. Then follow individual chapters which provide detailed accounts of the biology, ecology, and bionomics of such major taxonomic groups as squirrelfishes, hinds and groupers, jacks, snappers, grunts, goatfishes, butterfly and angelfishes, parrotfishes, surgeonfishes, triggerfishes, and spiny lobsters, spider crabs, and other crustaceans. Finally,

Munro assesses information on the potential harvests of commercially important reef fishes. In the epilogue, more recently developed stock assessment methods are used to reanalyze the data collected in the previous decade, and the advances made in that period are reviewed. Well illustrated, and with color plates of a dozen important commercial reef fishes, the volume provides a fine review of the region's coral reef fishery resources. Paperbound copies are available from ICLARM for $16.00 (surface mail) or $33.00 (airmail), and the hardback edition costs $19.50 (surface) and $37.00 (airmail). Like the other ICLARM publications, it is available in the United States from International Specialized Book Services, Inc. (ISBS), P.O. Box 1632, Beaverton, OR 97075, using the "airmail" price.

ICLARM Technical Reports 13 is **"An Atlas of the Growth, Mortality and Recruitment of Philippine Fishes"** by Jose Ingles and Daniel Pauly. The authors present the results of a detailed analysis (ELEFA program) of length-frequency data collected from 1957 to 1981 throughout the Philippines, covering 23 families (including 34 genera and 56 species) which represent 112 stocks of commercially exploited finfishes. The results are presented in the form of 112 plates. For each stock is provided: An outline drawing of the species discussed (including scientific name, sampling location and date), a recruitment pattern used to infer seasonality of spawning and recruitment, and a graph where probabilities of capture are plotted against length to estimate mean length at first capture. For each stock, a brief legend provides the numerical values of the estimates of growth, mortality, and exploitation rate; the source of the data used, brief comments on the biology of the fish, and sources of further information. (Price not listed but is available from both ICLARM or ISBS.)

Recent ICLARM publications on tilapias include Bibliographies 6, **"A Bibliography of Important Tilapies (Pisces: Cichlidae) for Aquaculture"** by Peter Schoenen. This new report lists published papers and reports on the following species: *Oreochromis variabilis*, *O. andersonii*, *O. esculentus*, *O. leucostictus*, *O. mortimeri*, *O. spilurus niger*, *Sarotherodon melanotheron*, and *Tilapia sparrmanii*. For each species is listed a separate bibliography, complete with subject and geographic indexes, and lists of synonyms and misidentifications. Paperbound, the volume costs $7.75 (surface mail) and $15.00 airmail.

Published as ICLARM Technical Reports 14 is **"Experimental Rearing of Nile Tilapia Fry (*Oreochromis niloticus*) for Saltwater Culture"** by Wade O. Watanabe, Ching-Ming Kuo, and Mei-Chan Huang. Presented are experiments made during 1983 at the National Sun Yat-Sen University, Institute of Marine Biology, Kaohsiung, Taiwan, which discuss the utility of early salinity exposure toward the saltwater culture of tilapias. (Price not listed.)

ICLARM Technical Reports 16 is **"Salinity Tolerance of the Tilapias *Oreochromis aureus*, *O. niloticus* and an *O. mossambicus* × *O. niloticus* Hybrid"** also by Watanabe et al. (Price not listed.) And ICLARM Conference Proceedings 10 is the **"Summary Report of the PCARRD-ICLARM Workshop on Philippine Tilapia Economics,"** edited by I.R. Smith, E. B. Torres, and E. O. Tan. Consisting mostly of abstracts of papers and reports of four working groups, the 45-page paperbound item is free of charge from ICLARM.

ICLARM Conference Proceedings 9, **"Theory and Management of Tropical Fisheries,"** edited by D. Pauly and G. I. Murphy, constitutes the results of an international workshop held jointly by the Fisheries Research Division of the Australian Commonwealth Scientific and Industrial Research Organization and ICLARM in Cronulla, Australia. The workshop was based on the premise that tropical countries were in urgent need of a coherent body of rules applicable to the management of their fisheries, many of which have been overfished.

Presentations include reviews of models in use or proposed, current research on stock assessment, and identification of major constraints on stock assessment and management. Other papers compare fish yields from a variety of tropical ecosystems, review the management of tropical multispecies fisheries, explore the realities of fishery management in the Southeast Asian region, and suggest directions for future research in tropical multispecies fisheries. The volume has indexes to geographical locations, names of authors or discussants, and species or taxonomic groups. Paperbound copies cost $17.50 (surface) and $28.50 (airmail); hardbound copies cost $21.50 (surface) and $35.50 (airmail).

Fisheries Technology Proceedings Published

The **"Proceedings of the Ninth Annual Tropical and Subtropical Fisheries Conference of the Americas,"** compiled by Ranzell Nickelson II, have been published by the Marine Information service, Sea Grant College Program, Texas A&M University, College Station, TX 77843 as TAMU-SG-85-106.

The volume contains 21 presentations, edited by their respective authors, relating to the unique problems of production, processing, packaging, distribution, and utilization of tropical and subtropical fishery species. Contributions range from a modified dilution procedure for bacterial examination of seafoods and the occurrence and distribution of *Salmonella* in the Suwanee River estuary to the repacking of fresh oysters, clams, and mussels, potential for problems with *Plesiomonas shigelloides*, planning for marketing jerky products, and processing and quality analysis of dehydrated seafoods. Other contributions discuss *Salmonella* survival in deep-fat fried breaded shrimp (experimental contamination), comparative analysis of shrimp block thawing methods, developing vessel level grade quality standards for the shrimp industry, rapid determination of *E. coli* in *Crassostrea virginica*, effect of salinity on flavor of penaeid shrimps, nutritional, chemical, microbiological, and organoleptical changes in breaded shrimp stored in wholesale and retail freezers, and other. Paperbound, the 344-page volume is available from the publisher for $12.00.

Authors, Titles, and Subjects in the *Marine Fisheries Review*, Vol. 47, No. 1-4, 1985

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Editorial Guidelines for the *Marine Fisheries Review*

The *Marine Fisheries Review* publishes review articles, original research reports, significant progress reports, technical notes, and news articles on fisheries science, engineering, and economics, commercial and recreational fisheries, marine mammal studies, aquaculture, and U.S. and foreign fisheries developments. Emphasis, however, is on in-depth review articles and practical or applied aspects of marine fisheries rather than pure research.

Preferred paper length ranges from 4 to 12 printed pages (about 10-40 manuscript pages), although shorter and longer papers are sometimes accepted. Papers are normally printed within 4-6 months of acceptance. Publication is hastened when manuscripts conform to the following recommended guidelines.

The Manuscript

Submission of a manuscript to *Marine Fisheries Review* implies that the manuscript is the author's own work, has not been submitted for publication elsewhere, and is ready for publication as submitted. Commerce Department personnel should submit papers under a completed NOAA Form 25-700.

Manuscripts must be typed (double-spaced) on high-quality white bond paper and submitted with two duplicate (but not carbon) copies. The complete manuscript normally includes a title page, a short abstract (if needed), text, literature citations, tables, figure legends, footnotes, and the figures. The title page should carry the title and the name, department, institution or other affiliation, and complete address (plus current address if different) of the author(s). Manuscript pages should be numbered and have 1½-inch margins on all sides. Running heads are not used. An "Acknowledgments" section, if needed, may be placed at the end of the text. Use of appendices is discouraged.

Abstract and Headings

Keep titles, heading, subheadings, and the abstract short and clear. Abstracts should be short (one-half page or less) and double-spaced. Paper titles should be no longer than 60 characters; a four- to five-word (40 to 45 characters) title is ideal. Use heads sparingly, if at all. Heads should contain only 2-5 words; do not stack heads of different sizes.

Style

In style, the *Marine Fisheries Review* follows the "U.S. Government Printing Office Style Manual." Fish names follow the American Fisheries Society's Special Publication No. 12, "A List of Common and Scientific Names of Fishes from the United States and Canada," fourth edition, 1980. The "Merriam-Webster Third New International Dictionary" is used as the authority for correct spelling and word division. Only journal titles and scientific names (genera and species) should be italicized (underscored). Dates should be written as 3 November 1976. In text, literature is cited as Lynn and Reid (1968) or as (Lynn and Reid, 1968). Common abbreviations and symbols such as mm, m, g, ml, mg, and °C (without periods) may be used with numerals. Measurements are preferred in metric units; other equivalent units (i.e., fathoms, °F) may also be listed in parentheses.

Tables and Footnotes

Tables and footnotes should be typed separately and double-spaced. Tables should be numbered and referenced in text. Table headings and format should be consistent; do not use vertical rules.

Literature Cited

Title the list of references "Literature Cited" and include only published works or those actually in press. Citations must contain the complete title of the work, inclusive pagination, full journal title, and the year, month, volume, and issue numbers of the publication. Unpublished reports or manuscripts and personal communications must be footnoted. Include the title, author, pagination of the manuscript or report, and the address where it is on file. For personal communications, list the name, affiliation, and address of the communicator.

Citations should be double-spaced and listed alphabetically by the senior author's surname and initials. Co-authors should be listed by initials and surname. Where two or more citations have the same author(s), list them chronologically; where both author and year match on two or more, use lowercase alphabet to distinguish them (1969a, 1969b, 1969c, etc.).

Authors must double-check all literature cited; they alone are responsible for its accuracy.

Figures

All figures should be clearly identified with the author's name and figure number, if used. Figure legends should be brief and a copy may be taped to the back of the figure. Figures may or may not be numbered. Do not write on the back of photographs. Photographs should be black and white, 8 × 10 inches, sharply focused glossies of strong contrast. Potential cover photos are welcome, but their return cannot be guaranteed. Magnification listed for photomicrographs must match the figure submitted (a scale bar may be preferred).

Line art should be drawn with black India ink on white paper. Design, symbols, and lettering should be neat, legible, and simple. Avoid freehand lettering and heavy lettering and shading that could fill in when the figure is reduced. Consider column and page sizes when designing figures.

Finally

First-rate, professional papers are neat, accurate, and complete. Authors should proofread the manuscript for typographical errors and double-check its contents and appearance before submission. Mail the manuscript flat, first-class mail, to: Editor, *Marine Fisheries Review*, Scientific Publications Office, National Marine Fisheries Service, NOAA, 7600 Sand Point Way N.E., Bin C15700, Seattle, WA 98115.

The senior author will receive 50 reprints (no cover) of his paper free of charge and 50 free copies are supplied to his organization. Cost estimates for additional reprints can be supplied upon request.

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